23. *The* Lower Carboniferous Succession *in the* North-West of England.

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[Plates XLIV–LVI.]

Contents.

		Page
I.	Introduction	449
II.	The Zonal Divisions	456
III.	The Shap and Ravenstonedale Districts. (Type Districts.)	484
IV.	The Arnside and Carnforth Districts	504
V.	The Kendal and Kirkby Lonsdale Districts	516
VI.	The Grange and Furness Districts	525
VII.	The Westmorland Pennines and the Middleton-in-Teesdale District	534
VIII.	Correlation with the South-Western Province and other Areas	544
IX.	Summary and Conclusions	548
X.	Palæontology	555

I. Introduction.

The Lower Carboniferous rocks of Westmorland and Cumberland crop out in a nearly continuous ring encircling the Lower Palæozoic rocks of the Lake District, broken only on the west by the overlap of the Triassic deposits. The south-eastern edge is situated in Yorkshire, and, though apparently continuous with the rest, is separated structurally by the Dent Fault; while the eastern margin of the ring is cut off from the Lower Carboniferous rocks of the Pennine Chain by the Pennine Fault, and by the mantle of Permian and Triassic rocks occupying the Vale of Eden.

The area dealt with in the present communication comprises some 400 square miles of country occupied by Lower Carboniferous rocks. It includes the whole of Westmorland and Yorkshire north and west of the Dent Fault, together with that portion of Lancashire which lies north of the Lune Valley. The small tract of Lower Carboniferous rocks, forming the northern extremity of Yorkshire, which lies between the Westmorland portion of the Pennine Chain and the River Tees is also included. The following are the points to which special attention has been given during the examination of the district:—

(1) The possibility of establishing a palæontological sequence from the base to the summit of the succession which would be applicable to the whole of the North-West of England.

(2) The general lithological characters of the different faunal horizons, and the variations which these undergo when they are traced laterally.

(3) The distribution of these faunal horizons in the area examined, and the relative dates of submergence of the pre-Carboniferous land-surface in the several districts included in this area.

(4) The possibility of applying the zonal succession determined for this area to the beds of corresponding age in Northumberland and Yorkshire, and of correlating this succession with that now established in the South-Western Province and elsewhere.
(5) The description of new or little-known fossil forms which have been met with during the examination of the area.

The investigation of the Lower Carboniferous rocks described in the following pages was begun as long ago as the year 1888, at the suggestion of Dr. J. E. Marr and the late Prof. Alleyne Nicholson. Throughout this investigation, and especially during the early stages of the work, I have received the greatest assistance from my friend and former teacher at Cambridge, Dr. Marr, and I am glad of this opportunity to acknowledge how much I owe to his help and encouragement.

By the year 1895, however, it was realized that the work of investigating the Carboniferous limestones of England in detail was too great a task for any one man, and a joint note was contributed to the British Association Meeting at Ipswich in 1895 [1] and subsequently to the 'Geological Magazine,' calling attention to the necessity of a detailed palæontological investigation of the Lower Carboniferous rocks. To further this object, a committee of the British Association was appointed in 1895.

For some years after this my attention was called to other matters, and my spare time was chiefly spent abroad.

In 1905 Dr. Vaughan read his now classical paper before this Society, and for the first time placed the zonal sequence of the Lower Carboniferous rocks of the Bristol District on a firm foundation. By his enthusiasm, eloquence, and the ungrudging way in which he has devoted his small amount of leisure to those who have sought his assistance, he has earned the gratitude of all who have the interests of British Stratigraphy at heart.

Dr. Vaughan's paper had the immediate effect of rekindling my interest in these rocks, and stimulated me to return once more to the scenes of my earlier work.

A preliminary account of the palæontological succession in Westmorland was given at the York Meeting of the British Association in 1906, and subsequently in the 'Geological Magazine.' [2] Since then further work has only served to confirm the general conclusions there stated.

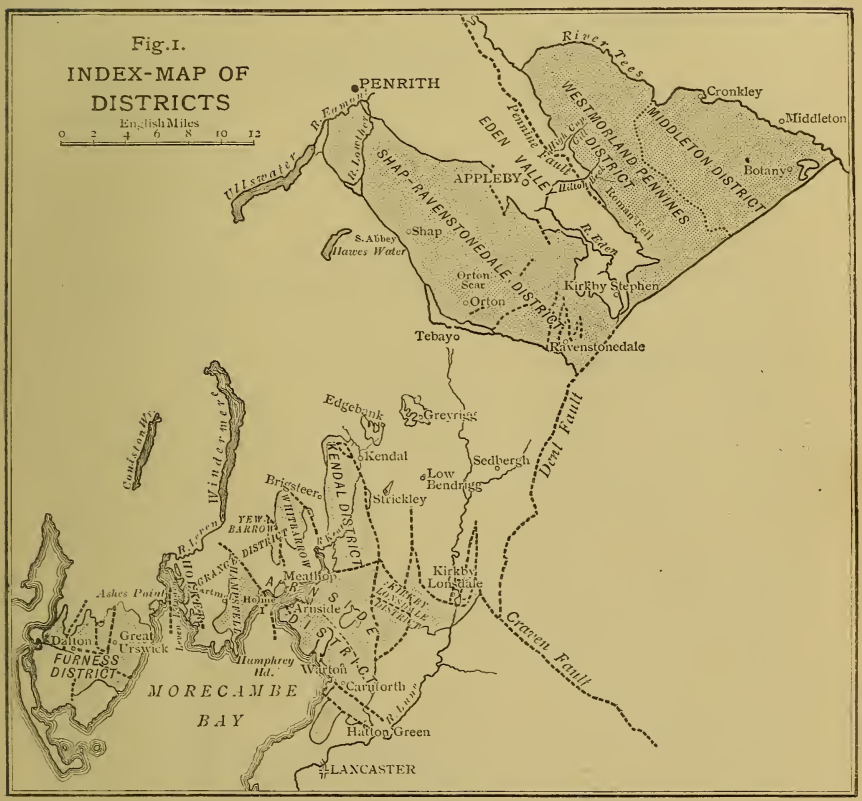
As a result of these investigations, it has been found possible to divide the Lower Carboniferous rocks of the North-Western Province into a series of zones, sub-zones, and bands, each of which is characterized, either by one species which is not found outside that particular subdivision, or by a collection of forms which do not occur in association at other horizons.

For convenience of description, the area dealt with is divided into the following districts:—

[1] Rep. Brit. Assoc. 1895, p. 696.
[2] Geol. Mag. dec. 5, vol. iv (1907) pp. 70-74.

(*a*) Shap and Ravenstonedale. (Type Districts.)
(*b*) Arnside and Carnforth.
(*c*) Kendal and Kirkby Lonsdale.
(*d*) Grange and Furness.
(*e*) The Westmorland Pennines and Middleton-in-Teesdale.

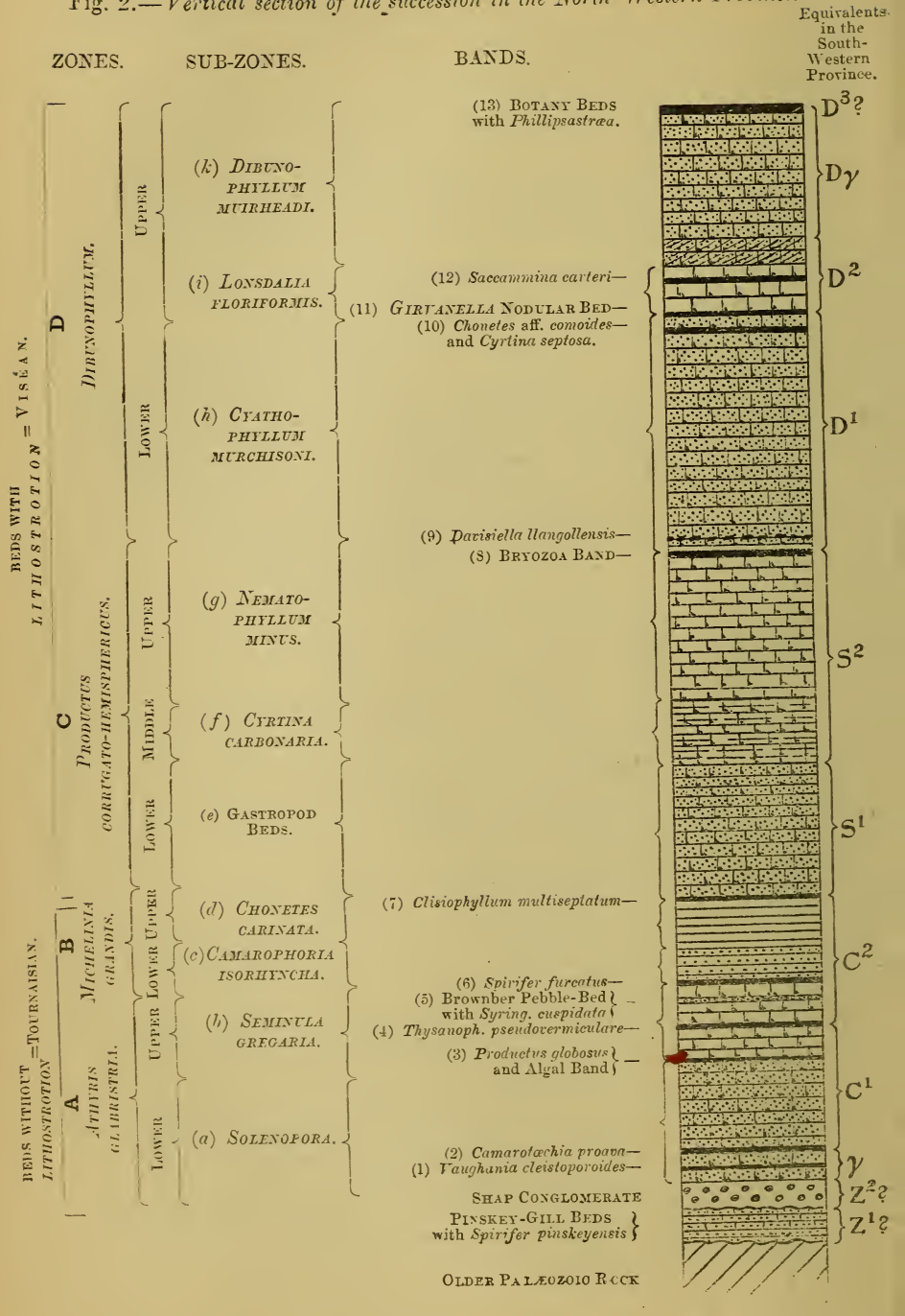
These districts, although they once formed portions of a continuous area of deposition, are now separated one from the other by tracts of Lower Palæozoic rocks, as the combined result of faulting and denudation.



The Shap and Ravenstonedale Districts are taken as the type districts for the area described, since they contain the complete sequence from the lowest horizon met with in the North-Western Province to the Millstone Grit. It was also in these districts that the zonal divisions were first established in detail.

In the accompanying table (fig. 2, p. 452) are set out the fossil forms which have been found most useful as indices for the different zones, sub-zones, and bands, on account of their wide distribution over the area dealt with.

Fig. 2.—*Vertical section of the succession in the North-Western Province.*



Although the general sequence tabulated in fig. 2 (p. 452) is applicable throughout the whole area under description, the detailed characters of certain portions of the succession vary in different parts of the area, so that parallel sections of districts situated far apart present at first sight considerable differences. When, however, the same levels are traced through the intermediate districts, the continuity of the faunal horizons can, as a rule, be readily established. For this reason two species have occasionally been cited as the indices for a particular band, since, although the two may occur together over a portion of the area, sometimes one and sometimes the other species may characterize the deposit when it is traced laterally into outlying districts.

For example, the band which lies near the summit of the Lower *Dibunophyllum* Sub-zone is characterized in the Grange, Arnside, and Furness districts by an abundance of *Cyrtina septosa*, together with somewhat rarer examples of *Chonetes* aff. *comoides*; while in the Shap District, at the same horizon, *Chonetes* aff. *comoides* occurs abundantly, but *Cyrtina septosa* is locally rare.

Any change in the fauna of any particular horizon when traced laterally is found to be accompanied, as a rule, by a corresponding lithological change; indeed, the fauna appears often to depend directly on the lithological character of the deposit, and one or more species may persist in a particular district into a higher horizon than is usual elsewhere, if the lithological character of the deposit remains unchanged. Thus *Cyrtina carbonaria*, which in the Kendal District is practically limited to its own sub-zone, is found in the Ravenstonedale District to persist into the base of the Lower *Dibunophyllum* Sub-zone. This local survival of *C. carbonaria* appears to be the direct result of the shallow-water phase, which in the Ravenstonedale District continued into the Lower *Dibunophyllum* Sub-zone, while elsewhere this sub-zone is coincident with a period of increased submergence. A good example of prolonged existence may also be cited from the same district, where the entrance of the typical fauna of the Lower *Dibunophyllum* Sub-zone is delayed, owing to the abnormal persistence of shallow-water conditions.

Another instance, of the influence exerted by the depth and character of the bottom on the distribution of a species, is found in the case of *Zaphrentis enniskilleni*. This species, which appears to have flourished only in shallow water, and preferably on a bottom composed of argillaceous material, enters at different horizons in the different districts. Thus, in the Arnside and Kendal Districts, it enters near the summit of the *Michelinia* Zone; in the Shap District it is found at the base of the Lower *Productus corrugato-hemisphericus* Zone, after the entrance of *Lithostrotion*; while, in the Ravenstonedale District, it occurs with several varieties near the summit of the Ashfell-Sandstone Series, immediately below the base of the *Cyrtina-carbonaria* Sub-zone.

A good instance of the association of a particular species with a definite type of deposit is afforded by *Syringothyris cuspidata*.

This species is practically confined to the *Seminula-gregaria* Sub-zone, and, though on the whole a rare shell in the North-Western Province, it sometimes occurs in fair abundance in the Eastern Districts, where it is invariably associated with arenaceous and oolitic deposits, and is especially characteristic of the Brownber Pebble-Bed. In the Western Districts, however, where this horizon is composed of calcareous rocks, it has scarcely ever been met with.

A further interesting feature which may be cited in this connexion, is the association of calcareous algæ with lagoon conditions. These organisms flourished only at three horizons in the North-Western Province, namely, in the *Solenopora* Sub-zone, at and near the base of the *Seminula-gregaria* Sub-zone, and again at the base of the Upper *Dibunophyllum* Sub-zone. In the first two cases the remains of calcareous algæ are closely associated with dolomitic deposits; while, in the last, clear but shallow-water conditions seem to have prevailed, in which masses of *Lithostrotion* and *Lonsdalia* grew somewhat after the manner of modern coral-reefs.

The most interesting lithological change met with in tracing the different horizons across the area from west to east occurs in the case of the *Michelinia* Zone and the beds immediately overlying it. This zone attains its fullest development in the Arnside and other western districts, where it contains one of the richest faunal assemblages found in the Lower Carboniferous rocks of the North-Western Province. In the Shap District and in the Westmorland Pennines this zone seemed, at first sight, to be entirely missing, and its apparent absence originally introduced a difficulty in correlating the individual beds of the Eastern with those of the Western Districts. The discovery, however, of *Michelinia grandis* in the *Camarophoria-isorhyncha* Bed at Shap proved conclusively, what had previously been strongly suspected, that the fossiliferous *Michelinia*-Beds of Arnside were represented in the Shap District by the almost barren deposits at the base of the Orton-Sandstone Series; while the corresponding horizon in the Westmorland Pennines has been found to lie in the oolitic grits and unfossiliferous sandstones underlying the Melmerby-Scar Limestone, along the foot of the Cross-Fell escarpment. This arenaceous deposit, the Orton and Ashfell-Sandstone Series, affords one of the most striking examples of the transgression of a definite lithological facies across a series of faunal lines. (See map, Pl. LIV.)

This sandstone episode, which in the Shap District occurs at the base of the *Michelinia* Zone, enters at a progressively later period as we travel southwards towards the Ravenstonedale District until, when we eventually reach the neighbourhood of the Dent Fault, the base of the Ashfell Sandstone is seen to lie some 100 feet above the base of the Lower *Productus corrugato-hemisphericus* Zone. At the same time, the faunas of both these zones gradually increase in importance as we pass southwards into the region where the sandstones are gradually replaced by calcareous rocks.[1]

[1] See map and description of the Shap and Ravenstonedale Districts.

The Bands.

These bands, at first sight, appear to indicate periods especially favourable for the development of certain organisms, but it is very doubtful whether this was really the case. It is equally probable that the bands are in many cases rich in certain species, not because the conditions were especially suitable for the growth of these organisms; but, on the contrary, paradoxical as it may seem, because the conditions were changing and becoming unfavourable: in consequence of which the organisms died more rapidly, and accumulated in greater relative abundance in a given thickness of deposit. The abundance of certain forms in a band would thus be due to a relatively sudden and drastic change of conditions, these forms being more affected than others: the change from a muddy to a sandy bottom, the variation in depth and temperature, the change from salt to brackish water, and the shifting of currents causing a change in the amount and character of the food-supply, would have different effects on different organisms according to their adaptability, their powers of locomotion, and their natural habitat. This view appears to be borne out by the fact that the bands are usually characterized by the abundance of certain species which occur also, though not so plentifully, in the underlying beds, but do not occur again above the bands which they characterize; and these are usually accompanied by other species which occur abundantly in the band, but are not again found above it. Further, the collection of species occurring in a band usually contains a large proportion of small immature individuals.

The division of the series into beds with and beds without *Lithostrotion*, given in fig. 2 (p. 452), is not intended so much as a stratigraphical subdivision, as a statement of fact. The names Viséan and Tournaisian are introduced out of deference to a wish expressed during the discussion which followed the reading of this paper; but, while I admit the priority of the subdivisions established for the Continental equivalents of these beds, these have, in my opinion, no real significance when applied to the rocks of the North-Western Province. There the Lower Carboniferous strata form a continuous series of marine deposits uninterrupted by any unconformity, the relative dates of submergence in the different districts depending essentially on the contour of the pre-Carboniferous land-surface. The sandstone episode which masks the palæontological succession in the Shap District is due, not to interrupted deposition, but to the introduction of detrital material from the east, consequent upon the submergence of the Pennine District at this period.

The palæontological break between the *Michelinia* Zone and the overlying *Productus corrugato-hemisphericus* Zone is no greater than that between the *Michelinia* Zone and the underlying *Athyris-glabristria* Zone, or between the Lower and the Upper *Dibuno-phyllum* Sub-zones.

During the progress of the work I have been indebted to many friends and geological colleagues for much kind help. I have already expressed my indebtedness to Dr. Marr and Dr. Vaughan, but am glad of this opportunity of acknowledging also the assistance received for some years past from students of University College, London. Among many others, I am especially indebted to Miss Edith Goodyear, B.Sc., and Mr. H. S. Bion, B.Sc., F.G.S., my assistants in the Geological Department at University College, who, together with Miss Munro, B.Sc., Mr. P. de G. Benson, B.Sc., F.G.S., and Mr. C. H. Cunnington, B.Sc., F.G.S., have for several years past accompanied me in the field. Without their ungrudging assistance it would have been impossible to have acquired the detailed information respecting the distribution of the zones set forth in the accompanying maps and description.

In the compilation of the fossil lists I am greatly indebted to Dr. A. Smith Woodward for the identification of the fish-remains; and to Miss Madeline Munro for the determination of the many forms of Bryozoa. The new forms met with during examination of this material are described in the appendices to this paper.

Finally, I should like to express my obligation to Dr. T. F. Sibly, for his kindness in reading the typescript of this paper, and for many valuable criticisms and suggestions.

II. The Zonal Divisions.

(A) The *Athyris-glabristria* Zone.

This zone includes the beds from the Shap Conglomerate up to the base of the *Michelinia* Zone, and, with the exception of the beds which underlie the conglomerate in Pinskey Gill, contains the oldest Carboniferous deposits in the North-Western Province.

The index-fossil ranges from the base of the zone to the lowest layer of the overlying *Michelinia* Zone. It is found at several horizons, and where present is generally abundant. No definite variants of zonal value can be distinguished at the different levels.[1]

Lithology.—The zone is characterized by impure limestones with occasional shaly partings. Many of the limestones are rich in magnesium carbonate, some containing up to 40 per cent. The magnesium carbonate appears always to be present combined as dolomite, and the little rhombohedra of this mineral are well seen in microscopic sections of the rock. The dolomitized beds frequently contain abundant geodes of calcite and dolomite. Many of the beds are porcellanous in texture, others are dun-coloured and somewhat earthy, and these are usually the richest in dolomite. Towards the summit of the zone, the deposits become

[1] Dr. Vaughan, who has kindly examined specimens from one of the lower horizons, reports that they include forms which are characteristic of Z 2 and C respectively in the Bristol District.

oolitic, while microscopic examination of numerous beds shows that foraminifera contribute largely to the calcareous portion of the formation throughout. A very interesting feature of the zone is the important part played by calcareous algæ as rock-builders, many layers at certain horizons being largely made up of the thalli of *Solenopora* and other more obscure forms.

The source of origin of the magnesium carbonate which is so constantly present in these beds is a question of some interest, and we may briefly review here the evidence bearing on this point, derived chiefly from the Shap District. This magnesium carbonate must either have been deposited contemporaneously with the rest of the rock, or have been introduced at some subsequent date. The latter is apparently the view taken by the officers of the Geological Survey, for they remark:

'In many places it [the limestone] is more or less dolomitic, apparently through the introduction of magnesium carbonate at some period subsequent to its deposition.'

If this view be adopted, the most likely source of the magnesium salts would be the waters of the Permian sea, but the Knipe-Scar Limestone, which overlies the Orton Sandstone, is practically devoid of magnesium carbonate; and it is difficult to see how the magnesium salts could have penetrated to the lower bed without affecting the overlying mass of limestone. If, on the other hand, the dolomitization was practically contemporaneous with the deposition of the beds, the magnesium salts must have been present in the Lower Carboniferous sea in which these limestones were deposited. That some shrinkage has taken place in the rocks since their deposition is shown by the abundance of drusy cavities present in the beds, and such shrinkage is well known to result from the conversion of calcareous rocks into dolomites. This shrinkage, however, would occur in any case, whether the dolomitization took place during Lower Carboniferous times or at any subsequent period. An interesting piece of evidence supporting the conclusion that dolomitization took place under the waters of the Lower Carboniferous sea, is furnished by the presence of drusy cavities in the Coniston Limestone, which is exposed immediately below the basement Carboniferous rocks in Blea Beck near Shap Wells. This limestone, which must have been exposed to the waters of the Lower Carboniferous sea, contains a considerable proportion of dolomite, apparently of secondary origin, and it is difficult to attribute this dolomitization to alteration during Permian times. This rock has been described by Mr. Harker & Dr. Marr.[1] It encloses pure white crystalline patches up to a quarter of an inch in diameter, which consist of clustered rhombohedra of unusually pure dolomite,[2] the carbonates of lime and magnesia being present in the rock in about equal proportions. Farther west, however, on the other side of the granite, where metamorphism

[1] Q. J. G. S. vol. xlix (1893) p. 367.
[2] See A. Harker, 'Petrology for Students' 4th ed. (1908) p. 271 & fig. 72.

of the Coniston Limestone has taken place, the proportion of magnesia to lime is only : : 3·65 : 11·50; this may be taken as the original relative proportion of these salts present in the limestone.

The bulk of the rock in Blea Beck, as shown by Mr. Harker, contains magnesium carbonate in addition to that found in the crystalline patches. The former may represent the magnesium originally present, corresponding to that found in the Coniston Limestone altered by the granite farther west; while the latter would then represent additional magnesia introduced after the intrusion of the granite, and therefore in Lower Carboniferous times. As shown by recent researches, when silicates are formed by metamorphism of magnesian limestones, the magnesia is always converted into silicates much more readily than the lime, and the abundance of lime-silicates in the metamorphosed portion of the Coniston Limestone seems to show that the rock contained but a small proportion of the magnesia before the intrusion of the granite.

It seems unlikely that the only outcrop of the Coniston Limestone known to contain a high percentage of crystalline dolomite should immediately underlie the Lower Carboniferous rocks (which also contain similar dolomitic geodes), unless the material of the geodes in both cases was derived from a common source. This fact, taken together with its absence from the overlying limestones, seems to point conclusively to the dolomitization having occurred in early Carboniferous times. It appears probable that this dolomitization is an expression of the shallow-water conditions which then prevailed. The deposition of the Shap dolomites in the depressions of the pre-Carboniferous land-surface suggests that lagoon conditions may have obtained during their formation, and in this connexion the reef-like masses of calcareous algæ, so characteristic of the lower portion of these beds, are of interest. Recent work on the origin of dolomite seems to point to the conclusion that the conditions most suitable for dolomitization occur in association with coral-reefs, in the formation of which calcareous algæ have been shown to play a conspicuous part.

In this connexion it is interesting to note that the other exposures of this horizon in the North-Western Province, namely those in the Ravenstonedale, Arnside, and Kendal Districts, are also rich in magnesium carbonate, and are again characterized by the abundance of *Solenopora* and other calcareous algæ.

We may conclude, then, that the dolomitization of the beds of the *Athyris-glabristria* Zone was practically contemporaneous with the deposits, in the sense that the coral-rock of the Funafuti Atoll and its dolomitization may be regarded as contemporaneous; that it took place under lagoon conditions in a subsiding area formed of the irregular pre-Carboniferous land-surface; and that these conditions were favourable to the growth of calcareous algæ, as in the case of recent coral-reefs.

Flora.—Calcareous algæ occur abundantly at two levels: namely, at the base of the lower and of the upper sub-zones respectively; while *Archæosigillaria vanuxemi* is apparently confined to this zone, but occurs at more than one level.

Fauna.—The fauna of this zone is, on the whole, a very distinctive one, and it is doubtful whether any of the forms pass up beyond the base of the overlying *Michelinia* Zone. The detailed account of the fauna will be best considered under the different subdivisions.

Geographical distribution.—This zone occurs in all the districts, but its full development is only found in the Shap and Ravenstondale Districts, where it attains its maximum thickness of 1335 feet. Elsewhere, as in the Westmorland Pennines, submergence took place at a somewhat later period, and only the upper portion of the zone is there represented. The zone may be divided into two sub-zones, which contain altogether six palæontological horizons or 'bands':—

Sub-zones.	Bands.
(*b*) *Seminula-gregaria* Sub-zone ...	(6) The *Spirifer-furcatus* Band. (5) The Brownber Pebble-Bed (*Syrinthyris-cuspidata* Band). (4) The *Thysanophyllum-pseudovermiculare* Band. (3) The *Productus-globosus* Band (with an algal layer at the base).
(*a*) *Solenopora* Sub-zone	(2) The *Camarotœchia-proava* Band. (1) The *Vaughania-cleistoporoides* Band.

(*a*) The *Solenopora* Sub-zone.

In this sub-zone are included all the beds from the base of the Shap Conglomerate to the base of the *Productus-globosus* Band. In the Shap District about 100 feet of beds may be assigned to this sub-zone, while in the Ravenstonedale District it reaches its maximum thickness of 1020 feet. The two districts are directly continuous, the lowest bed in each representing approximately the same horizon. This difference in thickness is due to the thinning of the individual beds when traced northwards, and not to any appreciable overlap of the upper beds on to the underlying Lower Palæozoic rocks. The interesting calcareous alga *Solenopora* has been selected as the index-fossil, on account of its presence throughout the sub-zone and its wide lateral distribution (Pl. XLVII, fig. 1). It has not been met with above the base of the *Productus-globosus* Band, but is found wherever the lower beds of the *Athyris-glabristria* Zone are developed in the North-Western Province. This organism has not previously been reported from the Upper Palæozoic rocks; indeed, it was hitherto known only from beds of Ordovician and Jurassic age. Its discovery in the Lower Carboniferous rocks of Westmorland, therefore, will assist

in bridging the gap which has so far appeared to exist in its vertical distribution.[1]

Lithology.—The character of the beds indicates shallow-water conditions following on the subsidence of a pre-Carboniferous area. The base of the zone is usually, but not always, composed of unfossiliferous conglomerate and red and yellow sandstones. Locally, as at the foot of Ullswater, north of Kirkby Lonsdale, and in the neighbourhood of Sedbergh, the beds are underlain by a coarse polygenetic conglomerate which has been attributed by several writers to torrential accumulations, laid down either in Upper Devonian or in Lower Carboniferous times.

The deposits near the base of the sub-zone are essentially shaly magnesian limestones; while, in the upper portion, the beds are more compact, and are frequently porcellanous, especially in the Ravenstonedale District. Many of the beds are almost unfossiliferous, and often contain drusy cavities. The detailed characters vary from place to place, and will be best described under the different districts.

Flora.

Solenopora garwoodi, sp. nov. Hinde MS.
Archæosigillaria vanuxemi Göppert.

Indeterminable remains, frequently abundant.

Fauna.

Hyolostelia cf. *smithii* (Young & Young). R.[2]

Aulopora sp.
Syringopora cf. *reticulata* Goldf.
Syringopora cf. *distans* Fischer.
Vaughania cleistoporoides gen. et sp. nov. (limited to special Band).
Zaphrentis aff. *costata* (M'Coy). R.
Zaphrentis densa Carr. R.
Zaphrentis koninckı Ed. & H. R.
Zaphrentis omaliusi Ed. & H.

Archæocidaris sp.
Palæchinus lacazei Julian.

Spirorbis cf. *caperatus* M'Coy. R.

Fenestella nodulosa Phill.
Fenestella plebeia Portl.

Crania quadrata M'Coy.
Orbiculoidea sp.
Athyris glabristria (Phill.). Abundant.
Athyris cf. *lamellosa* (L'Éveillé). R.
Camarotœchia proava (Phill.) (limited to special Band).
Derbya sp.

Productus cf. *globosus* sp. nov.
Productus cf. *punctatus* Mart.
Productus pyxidiformis de Kon. R.
Reticularia cf. *lineata* (Mart.).
Rhynchonella sp.
Rhynchotreta angulata (Linn.). M.
Schellwienella crenistria (Phill.).
Seminula aff. *ficoides* Vaughan.
Spirifer clathratus M'Coy. R.
Spiriferina cf. *octoplicata* (Sby.).

Modiola cf. *lata* (Portl.). S.

Conularia quadrisulcata Sby.
Euomphalus sp., large.
Murchisonia sp.
Straparollus sp.

Orthoceras sp.

Kirkbya costata Jones. R.
Leperditia.

Deltodus garwoodi, sp. nov. Smith Woodward.
Pleuroplax sp. nov.
Psephodus cf. *magnus* (M'Coy).

[1] This form, together with other calcareous algæ from the Lower Carboniferous rocks of Britain, will shortly be described by Dr. G. J. Hinde, F.R.S.

[2] S=limited to the Shap District; R=limited to the Ravenstonedale District; M=limited to Meathop (Arnside District).

Geographical distribution.—The full development of this sub-zone occurs only in the Shap and Ravenstonedale Districts. The upper portion is present at Meathop, and probably also on the western side of the Kendal outlier, and in the Furness District; but it is absent from the Pennine area, which was not submerged until a later period.

(*a* 1) The *Vaughania-cleistoporoides* Band.

This band consists of a yellow earthy dolomite a few feet thick, passing into more shaly beds above and below. It occurs about 20 or 30 feet above the base of the zone.

Geographical distribution.—It has only been met with in the Shap and Ravenstonedale Districts, and the index-fossil is connned to this band.

(*a* 2) The *Camarotœchia-proava* Band.

This band forms a well-marked horizon, about 80 to 100 feet above the Basement Conglomerate, in the Shap and Ravenstonedale Districts. The band reaches its greatest thickness in Ravenstonedale, and is characterized by the development of porcellanous magnesian limestones. It thins rapidly north-westwards, and disappears to the north of Shap. The fauna is scanty: it includes *Solenopora, Syringopora* cf. *reticulata*, *Seminula* aff. *ficoides*, and a large form of *Rhynchotreta angulata*.

Geographical distribution.—At the summit of the Abbey Cliff, Shap District. In Stone Gill, Piper Hole, etc. in the Ravenstonedale District. At Low Meathop in the Arnside District. Below Cunswick Scar in the Kendal District. Unknown in the Grange, Furness, and Pennine Districts.

(*b*) The *Seminula-gregaria* Sub-zone.

This sub-zone is comparatively thin. It includes the beds from the top of the porcellanous *Solenopora* series to the base of the *Michelinia* Zone. The index-fossil is shown in Pl. LI, fig. 5. It occurs in many of the layers, and is associated with a form resembling *S. ficoides* Vaughan. The base of the sub-zone is marked by the characteristic Algal Band.

Lithology.—In the Shap District the beds in the lower portion are compact and dolomitic, usually purple when freshly broken, abounding in drusy cavities, and often weathering to a dun colour. In the south of the district and in Ravenstonedale these beds take on a more shaly character; but in the upper portion of the sub-zone the beds become more calcareous, and are specially characterized by the development of oolites which are typical of this horizon in the North-Western Province. Associated with this oolitic development we frequently find an abundance of white quartz-pebbles, which are distributed over a wide area in the

eastern districts and occur chiefly at a definite stratigraphical level—the Brownber Pebble-Bed. This bed has proved of great value in determining the exact horizon of the lowest Carboniferous deposits in the Westmorland Pennine District. In the Kendal District, layers of china-stone occur locally near the base of the sub-zone, crowded with *Calcisphæræ* and allied forms.

Fauna.—In these beds fossils are usually scarce, and many of the dun limestones and dolomites are apparently unfossiliferous: they contain, however, ostracoda and foraminifera.

Of the four bands established in this sub-zone, enumerated above (p. 459), the three upper bands serve to link the lower beds of the type districts with those of the Westmorland Pennines on the east and with the Kendal and Grange Districts on the west; while the basal Algal Band has been traced in many of the districts.

Geographical distribution.—This sub-zone is well developed along the western escarpment of the Shap and Ravenstonedale Districts, where it reaches a maximum thickness of about 300 feet. At Meathop, in the Arnside District, about 80 feet of these beds are present, and contain a coral fauna of special interest. Their distribution in the Kendal, Grange, and Furness Districts is shown in dark green on the accompanying maps (Pls. LIII–LV). In the Westmorland Pennines, and at Lupton Row in the Kirkby-Lonsdale District, only the higher portion of this sub-zone has been met with.

(*b* 3) The *Productus-globosus* and *Rhynchonella-fawcettensis* Band.

The algal layer at the base of this band is of great interest, and is best developed in the Shap and Ravenstonedale Districts. It consists of a layer of shaly dun-coloured dolomite a few feet thick, in which are embedded dark calcareous nodules of a compact porcellanous texture weathering to a pale grey. These nodules average from 1 to 2 inches in diameter, and represent the thalli of calcareous algæ (see Pl. XLVII, fig. 2). In the district between Fawcett Mill and Ravenstonedale village, this shale is underlain by a more compact bed composed of reef-like masses of algæ, disposed in undulating layers, forming hemispherical domes with intervening depressions 3 to 4 inches in diameter. At least two different forms of algæ appear to be present in this layer, which can be traced at intervals between Shap Abbey and Ravenstonedale. It occurs also at the same horizon in the Kendal District; at Meathop in the Arnside District; and in the outliers between Kendal and Kirkby Lonsdale. It is of especial value for the correlation of the beds, in districts where *Productus globosus* itself has not been found.

The *Productus-globosus* Band marks a constant horizon throughout the Shap and Ravenstonedale Districts. It is not, however, clearly traceable in the districts to the west, and in the

Westmorland Pennines no Carboniferous rocks so low in the sequence have been met with. The beds are composed of alternations of compact dolomites and impure shaly limestones, and form a transitional series between the porcellanous beds of the *Camarotœchia-proava* Band below, and the more purely calcareous and oolitic rocks of the overlying beds. Where typically developed, *Productus globosus* is associated with *Pr. rotundus* and *Rhynchonella fawcettensis*. The last species being unknown in the North-Western Province outside this band, we may with advantage associate it with *Pr. globosus* as an index-fossil for this horizon. Near Shap Toll-Bar the beds are markedly dolomitic, and the fauna undergoes certain modifications, being characterized by its wealth in gastropod species.

The following fauna occurs normally in the *Productus-globosus* Band and overlying beds up to the base of the *Thysanophyllum-pseudovermiculare* Band [1]:—

Syringopora sp.
Zaphrentis cf. *omaliusi* Ed. & H.

Archæocidaris plates and spines.

Stenophragma lobatum, gen. et sp. nov. Munro. R.

Orbiculoidea cf. *nitida* (Phill.).
Athyris glabristria (Phill.).
Cyrtina cf. *carbonaria* (M'Coy). M. F. G.
Productus globosus, sp. nov. S. R.
Productus rotundus, sp. nov.
Rhipidomella michelini (L'Éveillé).
Rhynchonella fawcettensis, sp. nov.
Schellwienella sp.
Seminula aff. *ficoidea* Vaughan.
Seminula gregaria (M'Coy).
Spirifer sp.
Spiriferina sp.

Aviculopecten cf. *plano-clathratus* M'Coy. R.

Euomphalus sp. Very large. S. R.

Ostracoda. Abundant.

Deltodus sp.

(*b* 4) The *Thysanophyllum-pseudovermiculare* Band.

This band lies 25 to 50 feet above the base of the *Productus-globosus* Band, and forms a valuable horizon in the eastern districts. The band is usually composed of thickly-bedded, compact, grey limestones which are frequently oolitic; indeed, it forms the base of a series of oolitic deposits which persist into the *Micheliani* Zone in many districts. It is often cherty and occasionally contains a few white quartz-pebbles, foreshadowing the conditions that prevailed during the deposition of the overlying beds.

Fauna.

Cyathophyllum cf. *multilamellatum* M'Coy.
Caninia subibicina M'Coy.
Syringopora sp.
Thysanophyllum pseudovermiculare (M'Coy).
Fistulipora incrustans Phill. R.

Productus cf. *rotundus*.
Chonetes aff. *papilionacea* (Phill.). S. Small convex form.

Bellerophon costatus Sby.

[1] M=Meathop; F=Furness District; G=Grange District; S=Shap District; and R=Ravenstonedale District.

The index-fossil often occurs in reef-like masses up to 2 feet in diameter, which do not, however, form true coral-reefs, for they are often seen to lie in an inverted position: showing that they grew loosely attached to the bottom, and readily drifted after death. This fact in itself testifies to the prevalence of shallow-water conditions and to the presence of wave- or current-action at this period. *Caninia subibicina* first enters at this horizon in the Shap District, and persists to the summit of the *Michelinia* Zone in the Arnside District. At Rosgill and Ravenstonedale Moor, in the Shap District, we meet with the earliest examples of papilionaceous forms of *Chonetes*. The band is most fossiliferous in the Ravenstonedale District, where the lower layers are marked by the abundance of well-grown specimens of *Fistulipora incrustans*.

Geographical distribution.—Between Bampton and the Dent Fault in the Shap and Ravenstonedale Districts, an almost continuous outcrop (Shap village is built on the outcrop of this band). Along the western escarpment, and in the Grayrigg outlier, in the Kendal District. Near Broad Oak in the Grange District. In the Arnside District it has practically thinned out, and is absent in the Furness District. In the Westmorland Pennines it occurs only under Roman Fell, and serves here to mark the time when this district was first submerged under the Carboniferous Sea.

The beds immediately overlying the *Thysanophyllum* Band in the Shap District consist of a few feet of compact and oolitic limestones, occasionally abounding in specimens of *Bellerophon*. The beds thicken, and become more shaly when traced into the Ravenstonedale District. Above Brigsteer in the Kendal District they contain silicified specimens of *Cyathophyllum* cf. *multilamellatum*.

(*b* 5) The Brownber Pebble-Bed (*Syringothyris-cuspidata* Band).

This band depends for its value as a stratigraphical horizon chiefly on its lithological structure; at the same time, its fauna is decidedly characteristic. In its typical development it is confined to the Shap-Ravenstonedale and Pennine Districts, but it can just be traced in the Kendal District. The band is marked by a series of oolitic limestones and calcareous grits averaging 20 or 30 feet in thickness, enclosing layers of false-bedded conglomerate. This conglomerate is composed of white quartz-pebbles averaging about an inch in diameter (though occasionally much larger), embedded in an oolitic matrix. The layers of pebbles are very inconstant, and thicken and thin laterally. The band represents the most pronounced development of oolite in the North-Western Province. The quartz-pebbles appear to have been introduced by strong currents setting from the Pennine Area lying to the east, which was then being submerged for the first time and was undergoing marine denudation. The deposit is thickest in the neighbourhood of Roman Fell, and here the quartz-fragments are on the whole largest and the development of oolitic structure most pronounced.

Fauna.

Cyathophyllum cf. *multilamellatum* M'Coy.
Syringopora reticulata Goldf.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (M'Coy).
Schellwienella sp.
Productus cf. *hemisphericus* Sby.
Rhynchonella sp.
Spirifer furcatus M'Coy. Rare.
Syringothyris cuspidata (Mart.).

Bellerophon sp. Abundant.
Murchisonia cf. *angulata* Phill. Donald.[1]
Pleurotomaria sp.

The fossils are usually fragmentary, testifying to wave- or current-action. The characteristic fossil, almost invariably present in all exposures of this horizon, is *Syringothyris cuspidata*, which occurs locally in considerable numbers. Though sometimes present in the overlying beds, it is extremely rare, and the fullest development of this species is certainly at this horizon; it may, therefore, conveniently be used as the index-fossil to this band. In the Kendal District the band is represented by a hard calcareous grit, in which *Syringothyris cuspidata* is again the most abundant fossil.[2]

Geographical distribution. — Throughout the Shap and Ravenstonedale Districts; under Roman Fell in the Pennine District; below Cunswick Scar in the Kendal District. The band is of especial importance in determining the date of submergence of the Pennine District.

(*b* 6) The *Spirifer-furcatus* Band.

This forms a useful horizon near the summit of the *Athyris-glabristria* Zone. It is best developed in the Arnside and Grange Districts, and consists usually of an oolitic limestone, crowded with somewhat fragmentary shells which show signs of attrition. The index-fossil occurs locally in great abundance, and is somewhat variable in form; but many specimens closely resemble M'Coy's figure of *Sp. furcatus*.[3]

The following list includes species which occur in the upper portion of the sub-zone, above the *Thysanophyllum* Band:—

Carcinophyllum simplex, sp. nov. M.[4]
Lophophyllum meathopense, sp. nov. M.
Lophophyllum vesiculosum, sp. nov. M.
Carruthersella compacta, sp. nov. M.
Campophyllum ciliatum, sp. nov. M.
Zaphrentis koninckı, Ed. & H.

Seminula cf. *ambigua* (Sby.).
Athyris glabristria (Phill.).
Camarophoria isorhyncha (Phill.).
Derbya sp.
Productus cf. *punctatus* (Mart.).
Productus cf. *hemisphericus* (Sby.).
Reticularia cf. *lineata* (Mart.).
Spirifer furcatus M'Coy. Very abundant.
Spirifer sp.
Syringothyris cuspidata (Mart.). One specimen.
Rhynchotreta angulata (Linn.). M.
Rhynchonella sp.

Euomphalus pentangulatus (Sby.).
Bellerophon costatus Sby.
Naticopsis plicistria Phill.

[1] See Q. J. G. S. vol. xliii (1887) p. 621. These specimens were identified by her as probably the above.

[2] The name 'Brownber Beds' is derived from the outcrop of this band near Newbiggin Station: it was first applied to the pebble-bed by Mr. R. H. Tiddeman in the Geological Survey Memoir on Kendal, Sedbergh, Bowness & Tebay, 1888, p. 31.

[3] 'Synopsis Char. Carb. Limest. Foss. of Ireland' 1844, pl. xxii, fig. 12.

[4] M = Found only at Meathop, in the Arnside District.

Geographical distribution.—At the summit of the old quarries on Meathop Fell, Arnside District; at Beck Head, Cat Crag, and near Cartmel in the Grange District; in Docker Beck (Oatmeal Bed) and on Ravenstonedale Moor in the Shap District; in Scordale Beck, east of Roman Fell, in the Pennine District.

(B) The *Michelinia* Zone.

This zone, though of no great thickness, is one of the most important in the North-Western Province. It attains its fullest development in the Meathop-Arnside section, where it is well exposed and extremely fossiliferous. It has, for convenience, been subdivided into two portions, which are as a rule both lithologically and palæontologically distinct.

(*c*) The *Camarophoria-isorhyncha* Sub-zone.

This sub-zone is characterized by the presence of *Michelinia grandis*, associated with *Camarophoria isorhyncha*—an association that is never found outside this sub-zone. The base of the sub-zone usually rests on the *Spirifer-furcatus* Band, and passes up into the shaly beds which characterize the upper portion of the zone.

Lithology.—Where typically developed in the Western Districts, as at Elliscales and Frith Hall, the sub-zone consists of fairly massive limestones. In the Ravenstonedale District it is not well exposed, and appears to be very thin and somewhat more shaly than in the Grange District; while at Shap it is represented by a single bed of sandy and oolitic limestone at the base of the Orton Sandstone.

Flora and Fauna.

Archæosigillaria vanuxemi Göppert.

Cyathophyllum cf. *multilamellatum* M'Coy.
Michelinia grandis M'Coy.
Zaphrentis koninckı Ed. & H.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (Phill.).
Reticularia lineata (Mart.).
Spirifer furcatus M'Coy. Rare.
Derbya sp.

Bellerophon costatus Sby.

Specimens of *Michelinia* occur, measuring as much as 2 feet in diameter, which seem to be referable to *M. grandis* M'Coy, but differ from the type-specimen in the Sedgwick Museum by their much greater size and by the absence of an epitheca. They appear to belong to the same form as that which occurs abundantly at Ronaldsway (Isle of Man). *Camarophoria isorhyncha* is found in practically all exposures of this sub-zone, sometimes, as at Docker Beck (Shap), in great abundance. Although it makes its entrance in the North-Western Province in the Brownber Pebble-Bed, it is extremely rare there, and occurs plentifully only in the sub-zone

under description. It has never been found in the upper portion of the zone, and with the exception of two rolled specimens collected from the Ashfell Sandstone, no occurrence of this form above the present horizon is known. *Athyris glabristria* also occurs sparingly, together with a fine mutation of *Cyathophyllum multilamellatum*.

Geographical distribution.—This sub-zone is represented in all the districts. It is well exposed in Docker Beck in the Shap District; at Elliscales in the Furness District; at Frith Hall and Cat Crag in the Grange District; at Meathop in the Arnside District; and above Brigsteer in the Kendal District. In the Ravenstonedale District it cannot be clearly separated from the upper portion of the zone. It is represented by unfossiliferous sandstones in the Pennine District.

(*d*) The *Chonetes-carinata* Sub-zone.

The upper portion of the *Michelinia* Zone is especially characterized by the occurrence of large specimens of *Chonetes carinata* (nobis MS.), a species confined to this sub-zone in the North-Western Province.[1] It is associated with *Michelinia grandis* and *M. tenuisepta*, together with *Caninia cylindrica* and *Cyathophyllum multilamellatum*. The upper limit is defined by a band which is marked by the abundance of *Clisiophyllum multiseptatum* and *Zaphrentis enniskilleni*. The beds are best developed in the districts bordering Morecambe Bay, and are especially well exposed along the shore to the west of Arnside; the latter exposure may, therefore, be taken as the fullest development of this sub-zone. Complete sections showing the relation of the two sub-zones one to the other occur at Frith Hall on the Leven Estuary; above Brigsteer in the Kendal District; and at Elliscales in the Furness District.

Lithology.—The rock is essentially a grey calcareous mudstone, enclosing harder layers of cement-stone. Some of the beds are shaly, especially towards the summit. In the Ravenstonedale District the sub-zone is represented by a small thickness of red and grey calcareous shales; but here this sub-zone is not so distinctly differentiated from the underlying beds as in the Western Districts. At Docker Beck, in the Shap District, it is apparently represented by the lower unfossiliferous portion of the Orton Sandstone.

Fauna.—The fauna is, on the whole, the richest, both in species and individuals, of any horizon in the North-Western Province. It also contains some of the largest forms of corals and brachiopods. In addition to the species mentioned above, *Zaphrentis koninckı* and

[1] This form appears to be identical with *Chonetes* aff. *comoides* of Dr. Vaughan, Q. J. G. S. vol. lxi (1905) p. 295.

its variant *Z. kentensis*, together with a very large form of *Schellwienella* (cf. *crenistria*), are characteristic of this sub-zone. The following list is chiefly compiled from the exposures in the Arnside District:—

Amplexus sp. Rare.
Aulophyllum sp.
Caninia cf. *cornucopiæ* (Mich.).
Caninia cylindrica (Scouler) & variant.
Caninia subibicina M'Coy.
Clisiophyllum multiseptatum, sp. nov. (at the summit).
Cyathophyllum multilamellatum M'Coy.
Cyathophyllum (*Diphyphyllum*) *dianthoides* M'Coy.
Lophophyllum fragile, sp. nov.
Michelinia grandis M'Coy.
Michelinia tenuisepta Phill.
Syringopora distans Fischer.
Syringopora geniculata Thomson.
Zaphrentis koninckı Ed. & H.
Z. koninckı, forma *kentensis* nov.
Zaphrentis enniskilleni Ed. & H. and variants.

Rhombopora sp.

Athyris expansa (Phill.).
Athyris expansa, forma *sulcata* nov.
Chonetes papilionacea Phill.
Chonetes carinata, sp. nov. (MS.).
Dielasma cf. *hastatum* (Sby.).
Leptæna analoga (Phill.).
Schellwienella cf. *crenistria* (Phill.) (very large form).
Productus cf. *corrugato-hemisphericus* (small form).
Productus aff. *rotundus* sp. nov.
Productus laciniatus M'Coy.
Productus cf. *martini* Sby.
Productus cf. *pyxidiformis* De Kon.
Productus cf. *punctatus* Mart.
Rhipidomella michelini L'Éveillé.
Reticularia cf. *lineata* (Mart.).
Syringothyris cuspidata (Mart.). Rare.
Spirifer cf. *integricostus* (Phill.).
Martinia cf. *ovalis* (Phill.).

Conocardium aliforme Sby.

Baylea simplex De Kon.
Bellerophon sp.
Naticopsis plicistria Phill.
Platyschisma tiara Phill.
Schizostoma catillus Phill.

Polyrhizodus magnus M'Coy.

Geographical distribution.—At Arnside and Storth Road in the Arnside District. At Frith Hall, Park Head, near Cartmel, Longhowe End, and Broad Oak in the Grange District. At Plumpton, Gascow, Dalton, and Marton in the Furness District. In the Kendal District above Underbarrow, Brigsteer, Beethwaite Green, and at Kettlewell; also on the banks of the River Kent between Hawes Bridge and Levens Park. Near Lupton Hall in the Kirkby Lonsdale District. In the Docker-Beck section in the Shap District it is merged in the Orton Sandstone, but emerges from below it on Ravenstonedale Moor. Between Blea Flatt and Ashfell Farms, and in Tarn Sike in the Ravenstonedale District. In the Westmorland Pennines it appears to be represented by the unfossiliferous sandstone of Swindale Crag which underlies the Melmerby-Scar Limestone.

(*d* 7) The *Clisiophyllum-multiseptatum* Band.

At the summit of the zone occurs an important band of shale characterized by the abundance of *Clisiophyllum multiseptatum*, which is immediately overlain by beds containing the earliest examples of *Lithostrotion*. Though best developed in the Arnside District, this band occurs in all the Western Districts in the same position immediately below the base of the Gastropod Beds, and also at Tarn Sike (Ravenstonedale) in the Eastern Districts.

(C) The *Productus corrugato-hemisphericus* Zone.[1]

This zone is separated, for convenience of description, to include a group of beds lying between the *Michelinia* and the *Dibunophyllum* Zones. The name of the index-fossil was originally suggested by Dr. Vaughan, and is adopted here as representing the general type of *Productus* which is common throughout the zone. The form is not absolutely confined to this zone, for occasional specimens are met with in the upper portion of the underlying *Michelinia* Zone. There is no one species that can be cited as confined to the zone, and yet as characteristic of it throughout. This zone marks the passage between the lagoon and shallow-water phases characteristic of the beds of the lower zones and the clear and deeper-water conditions which obtained during the deposition of the beds of the overlying Lower *Dibunophyllum* Sub-zone. The fauna is also intermediate in character. The zone is present in all the districts, and may be subdivided as follows:—

Upper = *Lithostrotion (Nematophyllum)-minus* Beds.
Middle = *Cyrtina-carbonaria* Beds.
Lower = Gastropod Beds.

(*e*) The Gastropod Beds.

This sub-zone contains no one species that can be cited as an index, but is usually characterized by a rich assemblage of gastropods and other mollusca, such as *Bellerophon*, *Euomphalus*, etc.

Lithology.—The lower portion is a dark bituminous, somewhat shaly limestone, which in the Arnside and Grange districts passes gradually down into the underlying *Michelinia* Beds. In the districts where the *Cyrtina-carbonaria* Sub-zone is absent, the black limestone-beds are succeeded somewhat abruptly by the overlying compact white limestones of the *Nematophyllum-minus* Sub-zone.

Fauna.—In the Western Districts these beds contain many species in common with those of the underlying *Michelinia* Zone, but *Michelinia* and *Chonetes carinata* are absent. *Lithostrotion* is associated with *Bellerophon* and *Euomphalus*. *Seminula* occurs abundantly near the base, together with a large form of Diphyphylloid *Lithostrotion*. A similar fauna, including the same Diphyphylloid *Lithostrotion*, is found in the Ravenstonedale District. The fauna of the calcareous band which occurs in the Ashfell Sandstone of the latter district is, however, unique in the area, being rich in corals, especially in forms of *Lophophyllum ashfellense* and specimens of *Zaphrentis enniskilleni* and variants.

[1] This zone appears to represent almost exactly the *Seminula* Zone of the Avon Section. The index-fossil is described and figured by Dr. Vaughan as *Productus cora*, mut. S_2, in Q. J. G. S. vol. lxi (1905) p. 291 & pl. xxv, fig. 4.

Caninia cylindrica (Scouler). Rare.
Diphyphyllum cf. *lateseptatum* M'Coy.
Lithostrotion cf. *martini* Ed. & H.
Lophophyllum ashfellense, sp. nov.
Syringopora geniculata Phill.
Syringopora distans Fischer.
Zaphrentis enniskilleni Ed. & H. and variants.

Platycrinus sp.

Stenophragma gen. et sp. nov. Munro.

Athyris expansa (Phill.).
Athyris cf. *planosulcata* (Phill.).
Chonetes papilionacea Phill.
Dielasma sacculus (Mart.).
Productus corrugato-hemisphericus Vaughan.
Productus laciniatus M'Coy.
Productus productus Mart.
Productus pyxidiformis de Kon.
Pugnax cf. *pleurodon* (Phill.).
Reticularia aff. *lineata* (Mart.).
Schellwienella sp.
Seminula ficoidea Vaughan.
Martinia cf. *ovalis* (Phill.).

Allorisma sulcatum Flem.
Aviculopecten dissimilis Flem.
Conocardium aliforme Sby.
[1] *Cucullæa tenuistria* M'Coy.
[1] *Myalina crassa* Flem.
[1] *Myalina verneuili* M'Coy.
[1] *Nucula gibbosa* Flem.
Sanguinolites clavus M'Coy.
Sanguinolites subcarinatus M'Coy.

Bellerophon costatus Sby. Very abundant.
Bellerophon sulcatus Sby.
[1] *Bellerophon* (*Bucania*) *cornu-arietis* Sby.
[1] *Capulus trilobatus* (Phill.).
[1] *Euomphalus crotalostomatus* M'Coy.
Euomphalus pentangulatus Sby.
[1] *Euomphalus* (*Phymatifer*) *pugilis* Phill.
Straparollus acutus Sby.
[1] *Murchisonia kendalensis*.
Naticopsis ampliata (Phill.).
Naticopsis elliptica (Phill.).
Naticopsis elongata (Phill.).
Platyschisma helicoides (Sby.).
Schizostoma catillus (Mart.).

Psammodus rugosus Ag.
Psephodus magnus M'Coy.

The geographical distribution in the Western Districts is shown in the accompanying maps. In the Ravenstonedale District, the upper portion of the sub-zone is represented by the Ashfell Sandstone; while, in the Shap District, the whole of the sub-zone is included in the Orton Sandstone.

(*f*) The *Cyrtina-carbonaria* Sub-zone.

This sub-zone forms a well-marked horizon in the type districts. It is usually crowded with specimens of the index-fossil and with small gastropods, together with species of *Lithostrotion* and *Syringopora*. Its average thickness cannot exceed 50 feet. It is most fossiliferous towards its base, and passes up into the overlying *Nematophyllum-minus* Beds. Though *Cyrtina carbonaria* is especially abundant at this horizon, it is not absolutely confined to it everywhere. In the Arnside and Grange districts a few specimens (possibly referable to this species) occur at a much lower horizon, namely, in the upper portion of the *Athyris-glabristria* Zone, while in the Ravenstonedale District individual specimens persist into the base of the Lower *Dibunophyllum* Zone. In both these cases, however, they are associated with distinct faunas, and do not occur in anything like the same abundance as in this sub-zone.

Lithology.—The rock is a somewhat compact and gritty grey

[1] Preserved in Kendal Museum.

limestone, passing in places into more shaly and platy beds. The beds mark the beginning of the depression which reached its maximum in the overlying Lower *Dibunophyllum* Sub-zone. Except in the Kendal District, this horizon is usually notable for a considerable development of secondary silica, and the fossils are often preserved in beekite.

The fauna is characterized chiefly by the abundance of the index-fossil, together with *Seminula* and small gastropods, and by the absence of Orthotetinæ and *Chonetes*, while *Productus corrugato-hemisphericus* and *Lithostrotion martini* are still abundant. *Pugnax pugnus* is first met with in this sub-zone, but is very rare.

Fauna.

Cyathocrinus sp.

Archæocidaris plates.

Aulopora sp.
Lithostrotion martini Ed. & H.
Syringopora geniculata Phill.

Spirorbis sp.

Athyris planosulcata (Phill.).
Cyrtina carbonaria (M'Coy).
Productus corrugato-hemisphericus Vaughan.
Productus elegans M'Coy.
Productus laciniatus Sby.
Productus punctatus Mart.
Pugnax pugnus (Mart.).
Rhynchonella sp.
Rhipidomella michelini (L'Éveillé).
Seminula ficoidea Vaughan.
Spiriferina laminosa (M'Coy).
Spirifer bisulcatus Sby.

Bellerophon costatus Phill.
Bellerophon obsoletus M'Coy.
Flemingia sp.
Loxonema rugiferum Phill.
Murchisonia sp.
Pleurotomaria (Ptychomphalus) vittata Phill.
Pleurotomaria sp.
Rhineoderma fragile de Kon.
Schizostoma catillus (Mart.).
Straparollus sp.
Turbonitella biserialis (Phill.).

Psephodus magnus M'Coy.

Geographical distribution.—Typically developed along the base of the Shap-Ravenstonedale escarpment between Long Scar Pike and the Dent Fault, but dies away into the upper portion of the Orton Sandstone before reaching Shap village. In the old Kettlewell quarries and on Cunswick Scar in the Kendal District. In the Arnside and Grange Districts it cannot be distinguished as a separate horizon. In the Pennine Escarpment it appears to be represented by the unfossiliferous sandstone underlying the Melmerby Scar Limestone, in Swindale Beck and High Cup Gill.

(*g*) The *Nematophyllum-minus* Sub-zone.

This sub-zone forms one of the most important horizons, on account of its presence in all the districts throughout the North-Western Province. It is, however, much better developed in some districts than in others. In the type districts and on Kendal Fell it rests on the *Cyrtina-carbonaria* Sub-zone, but, where that horizon is absent in the Western Districts, the lower limit is taken at the base of the compact white limestone which rests upon the darker, more bituminous gastropod-beds of Red Hills under

Arnside Knott. This line is rather one of convenience than a strict zonal horizon, since the index-fossil is not found in the lowest compact limestone, which may indeed in part represent the *Cyrtina-carbonaria* Beds of the eastern districts. In the western districts the overlying Bryozoa Band is also absent, and the upper limit of the sub-zone is taken at the base of the Lower *Dibunophyllum* Sub-zone.

Lithology.—The rocks are always calcareous, and never dolomitic. They vary from compact white limestones to thinly-bedded calcareous shales. In the type districts and in the Westmorland Pennines they usually occur as a dark-grey, somewhat argillaceous and thinly-bedded limestone. Round Morecambe Bay the beds are divisible into a lower compact and an upper, thinly-bedded, shaly limestone, crowded with *Chonetes papilionacea*. In the Eastern Districts that form is practically absent, and the upper shaly *Ch.-papilionacea* Beds of Arnside Knott and Whitbarrow must include the horizon of the Bryozoa Band of the Eastern Districts. Where the sub-zone reaches its greatest development on Arnside Knott it cannot be far short of 330 feet in thickness; but, in the Shap District and along the Pennine Escarpment, the sub-zone is reduced to a comparatively thin deposit immediately overlying the Orton and Swindale Beck Sandstones, which probably include a part of this sub-zone, the upper portion only being represented by the lower portion of the Knipe-Scar and Melmerby-Scar Limestones.

Fauna.—*Nematophyllum minus* was described by M'Coy from specimens collected in the Kendal District. His name has, therefore, been retained, in order that the exact form characteristic of this sub-zone may be recognized with certainty, although (as pointed out on p. 564) it is undoubtedly a *Lithostrotion*, and this species may even be the genotype. The size of the corallites varies considerably, being smallest in the Eastern Districts, where siliceous deposits predominated in the lower portion of the sub-zone. In the Western Districts *Chonetes papilionacea*[1] occurs throughout the sub-zone, and is so abundant in the upper portion as to impart a fissile character to the limestone. So numerous are the individuals of this species that it might well give its name to the sub-zone, were it not that specimens are practically absent from the type districts and from the Pennine Escarpment, while *Nematophyllum minus*, as already mentioned, is found throughout. Again, forms which, though smaller, cannot be readily separated from this species of *Chonetes*, occur in the underlying portion of the zone, and even sparingly in the *Michelinia* Zone below. No other form is confined to this sub-zone, or can be deemed specially characteristic of it.

[1] This form is doubtfully referred to Phillips's species. The form alluded to here is that shown in fig. 5, pl. xlvi vol. ii of Davidson's 'Fossil Brachiopoda' (Monogr. Pal. Soc.) 1858–63.

Fauna.

Alveolites capillaris (Phill.).
Alveolites etheridgi Thomson.
Lithostrotion irregulare (Phill.).
Lithostrotion (Nematophyllum) minus M'Coy.
Syringopora geniculata Phill.
Syringopora sp.

Athyris cf. *expansa* (Phill.).
Chonetes papilionacea Phill.
Productus corrugato-hemisphericus Vaughan.
Productus cf. *fimbriatus* Sby.
Productus cf. *striatus* Fischer.
Seminula ambigua (Sby).

Bellerophon sp.
Murchisonia sp.
Straparollus sp.

Psephodus magnus M'Coy.

Geographical distribution. — Present in all districts throughout the North-Western Province.

(*g* 8) The Bryozoa Band.

This band forms a very constant horizon everywhere in the type districts, and is also well developed along the Pennine Escarpment. It has not been met with in the Western Districts, where it appears to be merged in the upper portion of the *Nematophyllum-minus* sub-zone. The western boundary of the area in which the Bryozoa Band was deposited lay roughly somewhere parallel to a line joining Sedbergh and Kidsty Pike. East of this line the Bryozoa Band is typically developed; while west thereof it is absent, and we find the *Chonetes-papilionacea* Beds instead. The difference was evidently due to the somewhat deeper and clearer character of the sea to the west of this line.

Lithology.—The band varies considerably in lithological character from place to place. It includes some 30 or 40 feet of rock, and forms a passage-bed between the *Nematophyllum-minus* Sub-zone and the Lower *Dibunophyllum* Sub-zone. The band represents a change in the character of the deposits, due probably to a slightly increased rate of submergence which changed the direction of the currents. It is alternately a shaly limestone, a compact porcellanous cementstone, and a hard yellow fragmental limestone. In the Pennine District it becomes more crystalline and somewhat bituminous.

Fauna.—The band is not always fossiliferous throughout. It includes one or more layers crowded with fossils, notably bryozoa, together with *Spiriferina laminosa* and *Aviculopecten dumontianus*. In the Shap District the band abounds locally with *Naticopsis plicistria*, Capulids and other gastropods; while in places, especially in the Westmorland Pennines, it is characterized by the interesting bryozoan *Stenopora compacta*. The porcellanous layers often contain numerous minute spherical bodies, which appear to be identical with the form described by Williamson from the Carboniferous Limestone near Mold under the name of *Calcisphera*. These bodies are now preserved in calcite, but it is impossible to determine whether this was their original condition, or whether they were originally composed of chitin or even silica. Mr. R. C. McLean,

in a recent note on these organisms,[1] in commenting on the poor mode of preservation usually exhibited by these forms in the Carboniferous Rocks, remarks:—

'This imperfection of outline strongly suggests that replacement of the original substance by secondary calcite has taken place. . . . . It is noticeable that some species of Calcispheræ have left carbonaceous remains which suggests that they too might have been chitinous in life.'

Mr. McLean throws out the suggestion that these *Calcispheræ* may have developed from true radiolaria by becoming adapted to brackish waters. It is interesting to note in this connexion the invariable association of the *Calcispheræ* with abundant plant-remains in the deposits of the North-Western Province (Pl. XLVII, fig. 4).

Fauna.

Pemmatites constipatus Hinde.

Alveolites etheridgi Thomson.
Lithostrotion martini Ed. & H.

Archæocidaris sp.

Stenopora compacta, sp. nov. Munro.
Cystodictya sp.
Fenestella membranacea (Phill.).
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
Fistulipora incrustans (Phill.).
**Hemitrypa hibernica* M'Coy.
Tabulipora sp.
Polypora sp.
Rhabdomeson sp.
Rhombopora sp.

Chonetes cf. *hardrensis* Phill.
**Athyris* cf. *expansa* (Phill.).
Crania cf. *quadrata* (M'Coy).
Cyrtina carbonaria (M'Coy).
Productus corrugato-hemisphericus Vaughan.
Productus laciniatus M'Coy.
Productus cf. *martini* Sby.
Productus cf. *maximus* M'Coy.
Productus punctatus Mart.
Pugnax pleurodon (Phill.).
**Pugnax pugnus* (Sby.).
Rhynchotreta angulata (Linn.).
Seminula ambigua (Sby.).
Seminula ficoidea Vaughan.
Spirifer bisulcatus Sby.
Spirifer duplicicostus Phill.
Spiriferina laminosa (M'Coy).

Myalina verneuili M'Coy.
Aviculopecten dissimilis Flem.
Pterinopecten dumontianus de Kon.

Bellerophon scalifer de Kon.
Capulus sp.
Naticopsis plicistria (Phill.).
Pleurotomaria sp.

Pleuroplax woodi Davies.

[* = Pennine District.]

Geographical distribution.—Throughout the Shap and Ravenstonedale Districts. In the Westmorland Pennines, in the Melmerby-Scar Limestone east of Roman Fell.

(D) The *Dibunophyllum* Zone.

The beds which succeed the *Productus corrugato-hemisphericus* Zone appear to correspond generally with the *Dibunophyllum* Zone of the South-Western Province. The highest limestones, however, as, for instance, those at Botany, and possibly a portion of the underlying Yoredale Beds, represent a horizon comparable to some portion of the D_3 Beds of Derbyshire. The zone may be considered under two divisions:—

[1] 'A Group of Rhizopods from the Carboniferous Period' Proc. Camb. Phil. Soc. vol. xvi, pt. 6 (1912) p. 512.

(*h*) The Lower *Dibunophyllum* Sub-zone.

This sub-zone is notable for its great thickness, for the purity of its limestones, and for its uniformity throughout. It represents the period of greatest submergence in the North-Western Province, and consequently presents very similar characters throughout the different districts. It can also be readily correlated with the beds of the corresponding age in the South-Western Province; and, as there can be no doubt regarding the contemporaneity of this sub-zone with the Lower *Dibunophyllum* Sub-zone of the Bristol District, we may adopt Dr. Vaughan's nomenclature without fear of causing confusion in the future.

Lithology.—The sub-zone is characterized over the greater part of the North-Western Province by the occurrence of somewhat massive grey and dove-coloured limestones, and by the complete absence of shaly partings or sandy intercalations. The rock is made up entirely of foraminifera and microscopic fragments of calcareous organisms in which the larger fossils are embedded. The sub-zone is remarkable for the development of certain structures, namely, (1) 'spotted' beds and (2) 'pseudo-breccias.' These occasionally pass into one another, but are usually distinct.

The 'Spotted' Beds.

These are especially characteristic of the base and summit of the sub-zone. They consist of small spherical patches of darker limestone surrounded by a lighter matrix, the dark spots averaging an inch in diameter. At a distance, therefore, a broken surface resembles a conglomerate rather than a breccia: on closer inspection, however, the edges of the dark spots seem to fade gradually into the matrix, and are evidently not of fragmental origin, both portions of the bed having been deposited contemporaneously. The spots are not typical concretions: for they exhibit neither concentric nor radial structure, and do not separate readily from the matrix on weathering. Again, in the majority of examples analysis shows no marked or constant difference between the chemical composition of the spots and that of the matrix. This is especially the case with the spotted beds which occur so constantly near the base of the sub-zone. Microscopic examination throws but little light on the origin of the spots: sections show that portions of the rock are richer in foraminifera than others, and sometimes these organisms seem to be more densely packed in the spots than in the matrix; but this arrangement does not by any means obtain generally, and appears to be accidental. So far as can be ascertained, the spots are due to a slight tendency to concretionary action, but this action has been practically confined to the coloured impurities in the original deposit, which have been concentrated locally to form the dark spots, leaving the bulk of the rock nearly free from colouring-matter. Since the rock is almost a pure limestone, the amount of material capable of being affected by concretionary action must have been very slight. The foregoing remarks apply

to the typical 'spotted' limestones found in the lowest beds of this sub-zone.

There are, however, other 'spotted' beds showing evidence of the separation of a definite portion of the deposit to form spots, which have a mineral composition different from that of the matrix; and these beds may throw light on the more obscure cases just described. The best example of this second type occurs in the Melmerby-Scar Limestone of Great Rundal Beck in the Pennine District. In this rock the spots are rather more nodular in character than usual, and the rock has a tendency to weather irregularly, the spots standing out slightly in relief. A fractured surface also shows the same tendency, pointing to the conclusion that the spots are denser and more compact than the matrix. On the other hand, the spots are readily attacked by acid, while the matrix, though easily disintegrated, leaves a large proportion of insoluble residue. In microscopic sections, the mineral composition of the spots and the matrix, unlike the examples previously described, proves to be essentially different: for, whereas the dark spots are composed, as usual, of fragmentary organic remains, foraminifera, and calcite-crystals, the lighter-coloured matrix is largely composed of subangular quartz-grains embedded in calcite. The matrix also presents somewhat the appearance of the 'flow-structure' of a rhyolite (Pl. XLVII, fig. 3). In the Melmerby-Scar rock, then, we find definite evidence that segregation of material has taken place, the fragmentary calcareous portions having collected together in patches, while the quartz-grains constitute the enveloping matrix; at the same time, the coloured impurities have also concentrated in the calcareous portions, giving rise to the dark spots.

The study of these different occurrences would thus appear to show that two types of 'spotted' rocks occur: in the first, which is by far the commoner—where the rock consisted originally of a nearly pure calcareous deposit—the concretionary action was necessarily limited to the concentration of the colouring-matter round centres to form dark spots; in the second case—where the original deposit contained a considerable proportion of sand-grains—a more marked concretionary action took place: the calcareous fragments together with the colouring-matter being concentrated in the spots, leaving the sand-grains to form a pale-grey matrix, in which the darker concretionary spots lie embedded. Though this seems to be essentially what has taken place, the actual process by which the calcareous material in the second case has effected a separation from the quartz-grains is not so easy to understand, for the quartz-grains evidently represent original detrital quartz, and not silica which has been introduced subsequently in solution. The concentration of one substance in a deposit to form concretions, as in the case of flints in Chalk or the nodules in the Magnesian Limestone of Durham, has generally been regarded as a chemical process affecting material in solution, or at least in a colloid state; but, in the present case, it would appear to require the actual migration of the foraminifera

and other calcareous fragments and their mechanical separation from the sand-grains, for these grains must have been originally distributed uniformly throughout the deposit. It is true that a ground-mass of crystalline calcite exists throughout the rock, which may have been in solution while the concentration of the calcareous elements took place, and may thus have facilitated the migration of the fragments and the coloured impurities during the consolidation of the deposit.

The development, then, of 'spotted' beds would seem to be the result of a greater or less manifestation of concretionary action, depending upon the relative purity of the original deposit. This concentration of the material to form the spots appears to have taken place during the consolidation of the deposit, and not at any subsequent period; it may therefore be regarded as pene-contemporaneous.

The 'Pseudo-Breccias.'

These are practically limited to the higher portions of the sub-zone. The rock varies in appearance, from a somewhat concretionary-looking nodular limestone to an angular breccia of which the fragments measure several inches across. The structure differs from that of the 'spotted' beds in two ways; in the first place by the more rugged and angular character of the darker patches when these are present, and secondly by the manner in which the rock weathers. As a rule, it is composed of similar fragments which cannot be differentiated into inclusions and matrix, and the mode of origin of these breccias is evidently different from that of the spotted beds described above. It appears to be due to weathering along definite irregular lines of strain set up in the rock either during, or subsequent to, consolidation (most probably the former), rather than to the separation of material by concretionary action. In fact, the lines would appear to be analogous to the spheroidal structures observed in basaltic rocks, and attributed to the strain set up on cooling and consolidation.

These beds of 'pseudo-breccia' form the higher dip-slopes of the Lower *Dibunophyllum* Sub-zone in all the districts. They are specially well developed on Hampsfell and along the coast, in the Grange and Arnside Districts.[1]

Fauna.—*Cyathophyllum murchisoni* occurs throughout the sub-zone, and *Dibunophyllum* and *Carcinophyllum* also occur abundantly—the latter being especially characteristic of the upper portion, which also contains rare examples of *Aulophyllum* cf. *pachyendothecum*. Many of the beds are rich in *Lithostrotion martini* and *L. junceum* in the higher layers, especially in the Ravenstonedale District. Both *Alveolites etheridgi* and *A. capillaris* are locally abundant. Large Campophyllids are also characteristic of the

1 Since this paper was read, Mr. E. E. L. Dixon has described similar structures in the limestones of South Wales; see Q. J. G. S. vol. lxvii (1911) pp. 507–11.

higher portion of the sub-zone. *Productus* cf. *maximus* (M'Coy) appears to be confined to this sub-zone. *Cyrtina septosa* enters in the upper portion, but only becomes abundant in the band which it especially characterizes near the summit, and the same statement applies to *Chonetes* aff. *comoides*. The following list includes the species most generally met with:—

Alveolites capillaris (Phill.).
Alveolites etheridgi Thomson.
Aulophyllum cf. *pachyendothecum* Thomson, at the summit.
Campophyllum sp. (Caninoid.)
Carcinophyllum θ Vaughan.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum φ Vaughan.
Dibunophyllum cf. *muirheadi* Nich. & Thomson.
Lithostrotion junceum (Flem.), coarse form.
Lithostrotion martini Ed. & H.
Lithostrotion portlocki (Bronn).
Syringopora geniculata Phill.
Syringopora sp.

Stenophragma grandyense, gen. et sp. nov. Munro.

Cyrtina septosa (Phill.). Rare.
Dielasma cf. *sacculus* (Mart.).
Productus cf. *cora* D'Orb.
Productus laciniatus M'Coy.
Productus cf. *maximus* M'Coy.
Productus cf. *martini* Sby.
Spirifer bisulcatus Sby.
Spirifer striatus Mart.

Allorisma sp.
Conocardium aliforme Sby.

Bellerophon sp.
Flemingia sp.

Geographical distribution.—The sub-zone occurs in all the districts, but it has been almost entirely denuded from the neighbourhood of Kendal. Its detailed distribution is shown on the maps (Pls. LIII–LV). In the Shap District it forms the greater portion of the escarpment and dip-slopes of the Knipe Scar Limestone, and along the Cross-Fell escarpment constitutes the whole of the Melmerby-Scar Limestone above the Bryozoa Band. In the Ravenstonedale District only the lower portion of the zone is present, and this is overstepped at Kirkby Stephen by the Permian deposits. As we go northwards from here, however, higher beds are seen to crop out successively from beneath the lower Brockrams, until, in the neighbourhood of Crosby Garrett, the highest beds of the zone are exposed. The sub-zone bulks largely in the Kirkby Lonsdale District, in the eastern portion of the Arnside District, in the Grange District, and in the eastern portion of Furness. Nearly everywhere it forms the summit of the limestone hills, notably Farlton Knott, Wharton Crag, Whitbarrow, Hampsfell, Birkrigg Common, and many minor elevations.

(*h*9) The *Daviesiella-llangollensis* Band.

This interesting band is confined to the southern end of the Shap and Ravenstonedale Districts, where it appears to lie a little above the base of the Lower *Dibunophyllum* Sub-zone, as shown by its position relative to the Bryozoa Band and by its association with *Productus* cf. *maximus*. No specimens of *Dibunophyllum* have, however, been found associated with it. *Daviesiella llangollensis* would seem, therefore, to have entered the North-Western Province slightly later than it appeared in North Wales, as its horizon in the latter region is usually assigned to S_2 of the South-Western Province.

(*h* 10) The *Chonetes*-aff. *comoides* and *Cyrtina-septosa* Band.

This band forms a well-marked horizon, a few feet thick, at or near the summit of the sub-zone. In the type districts it consists of a thin bed of very pure platy limestone, which lies about 15 or 20 feet below the base of the lowest Yoredale sandstone. It is everywhere characterized by the abundance of *Chonetes* aff. *comoides*, associated with *Cyrtina septosa* and a small form of *Productus striatus*.

The form of *Chonetes* aff. *comoides* so characteristic of this band appears to be identical with that figured by Dr. Vaughan[1]; it does not differ essentially from Sowerby's type, except that the shell is, as a rule, less thickened. In the Western Districts the band is of a pale buff colour, is usually slightly dolomitic, and contains abundant remains of *Cyrtina septosa*. The band is associated with beds of 'pseudo-breccia,' and underlies a compact nodular bed the surface of which is covered with stick-like concretions, a bed that occurs at this horizon over the whole of the Morecambe-Bay area (Pl. XLVI, fig. 2, facing p. 518).

Geographical distribution.—The band is shown by a special symbol on the accompanying maps (Pls. LIII–LV). It occurs in most of the districts where the highest layers of the Lower *Dibunophyllum* Sub-zone are exposed, notably on the dip-slopes at Grandy and on Gathorn Plain in the Shap District; along the coast in the neighbourhood of Jenny Brown's Point in the Arnside District; on Grange shore, Holm Island, and at Humphrey Head in the Grange District; also in Little Urswick Quarries and along the coast-line in the Furness District. The band is not distinctly marked in the Westmorland Pennines; but a similar layer, separated by some 40 feet of rock from the base of the Upper *Dibunophyllum* Sub-zone, occurs in West Yorkshire between Ribble Head and Great Whernside, where the band again appears in the form of a yellow dolomite, and contains casts of large specimens of *Cyrtina septosa*. The specimens figured by Phillips[2] and Davidson[3] appear to have been collected from this band.

(*i* & *k*) The Upper *Dibunophyllum* Sub-zone.

This sub-zone comprises by far the thickest series of deposits of the Lower Carboniferous sequence in the North-Western Province, and marks the return of shallower water; the conditions, however, differed considerably from those which obtained during the deposition of the *Athyris-glabristria* Zone. The same conditions must have prevailed over a large area in Westmorland, Lancashire, Cumberland, Durham, Northumberland, and Yorkshire; and, as in the case of the lower sub-zone, there appears to have been direct connexion also with the South-Western Province, at all events, at the beginning of the period, for *Lonsdalia floriformis* marks the

[1] Q. J. G. S. vol. lxi (1905) p. 295 & pl. xxvi, fig. 4.
[2] 'Illustrations of the Geology of Yorkshire' vol. ii (1836) pl. xi, fig. 7.
[3] Monogr. Pal. Soc. 'Brit. Foss. Brachiopoda' vol. ii (1858–63) pl. xiv, fig. 8.

lower stage of the sub-zone almost everywhere throughout the country. In the Eastern Districts the beds belong to the Yoredale type of Phillips and the Geological Survey. The base of the sub-zone is, for convenience, taken at the lowest sandstone which there overlies the Melmerby or Knipe Scar Limestone, as it ushers in the change in lithological character. The upper limit of the sub-zone is much more difficult to define, and in one district at least (the Pennine District) the sub-zone persists well up into beds mapped as Millstone Grit by the officers of the Geological Survey. The separation of these beds into two divisions represented by the symbols D_2 and D_3 in other areas, cannot be satisfactorily attempted at present in the North-Western Province. This is due to the almost complete absence of *Cyathaxonia* Beds, examples of this genus being extremely rare and confined, so far as is known, to local occurrences in the Westmorland Pennine District; while no beds referable to the Pendleside Series have been met with in the districts described.

Another difficulty is introduced by the marked difference in the lithological and palæontological characters presented by the higher beds of the *Dibunophyllum* Zone in the Eastern and Western Districts respectively. Unfortunately, these beds have been denuded from the greater part of the Western Districts, so that the exact areas originally occupied by the two types and the character of the passage from one to the other cannot now be definitely stated. Of the portions still remaining, the northern and eastern outcrops, forming the Shap-Ravenstonedale and Pennine Districts, belong to the 'Yoredale' type, while the Southern and Western Districts belong to what we may, for convenience of description, call the Western or 'Kirkby Lonsdale' type. These two types are now separated over the greater part of the area by a wide tract of Lower Palæozoic rocks, although the eastern margin of the Kirkby Lonsdale District lies within 2 miles of the Yoredale rocks of Casterton Fell, from which, however, it is separated by the Dent and Craven system of faults.

It is no part of the object of this communication to enter into a detailed discussion of the causes which produced this difference in the character of these two types. The writer, however, has long been of the opinion that, although the change from the Yoredale type of deposits, now found north of the Craven Faults, to that found on the south side must originally have been a gradual one, the close proximity of these two types east of Kirkby Lonsdale at the present day suggests that here, at all events, the two types have been brought into their present positions by tectonic movements. This view was expressed by Dr. Marr as long ago as 1899, for he remarked in his work on the Limestone Knolls in the Craven District of Yorkshire that

'the Middle Craven Fault, in fact, appears to be a thrust-plane inclined downward towards the north . . . . . if the fault be a thrust the disposition of the rocks is perfectly explicable . . . . . if my interpretation of the structures south of the fault be true, these structures require thrusting to account for them.' (Q. J. G. S. vol. lv, 1899, pp. 352–53.)

(1) The Yoredale type.—This type is limited to the Shap and Pennine Districts.

Lithology.—The beds resemble generally the Yoredale rocks of the type area in Wensleydale, and also the well-known development of these beds on Ingleborough and Penyghent. They consist of alternations of limestones and sandstones, with subordinate shales and occasional thin coal-seams. The limestones vary in number in the two districts: eleven distinct beds being recognized in the Shap area, and fifteen in the Cross-Fell range. Occasionally one or two of these may unite to form a single thick limestone, as in the case of the Brackenslack and Maulds-Meaburn-Edge Limestones, which unite in the northern portion of the Shap District to form the Lowther Limestone. The exact correlation of the individual limestones of the two districts is not, however, of importance, except in so far as they contain similar faunas. The rocks in the two districts appear to have been deposited in direct continuity, and are only now separated as a result of the denudation which has taken place on the upthrow side of the Pennine Fault. The limestones are, as a rule, dark, impure, and ferruginous; they are frequently crinoidal, while many of them are markedly bituminous. Some are argillaceous, and these show a tendency to nodular and concretionary structures. The lower beds are usually fairly fossiliferous in both areas, but the fossils are seldom well-preserved. In the Shap District the higher beds are almost barren, and are locally dolomitized and impregnated with silica and hæmatite. In the Pennine District the corresponding beds are much richer in fossils. The sandstones are seldom fossiliferous, except in the neighbourhood of Middleton-in-Teesdale, where one bed occurs near the summit of the Yoredale Series crowded with casts of *Spirifer* cf. *bisulcatus*. The shales are quite subordinate in the Shap District, and are seldom exposed. In the Pennine area, however, several beds of black shale occur, which are often crowded with bryozoa and small brachiopods.

The Yoredale Beds may, for convenience of description, be considered under two divisions:—

	Bands.
Upper, with *Dibunophyllum muirheadi* abundant.	'Botany Beds.' *Phillipsastræa* Band.
	Saccammina-carteri and *Productus-edelburgensis* Band.
Lower, with *Lonsdalia floriformis* and *Cyathophyllum regium*.	*Productus*-cf. *giganteus* Band.
	Nodular *Girvanella* Bed. (At the base.)

The lower division with *Lonsdalia floriformis* includes all the beds, from the lowest sandstone to the base of the Maulds-Meaburn Limestone of the Shap District or the Jew Limestone of the Pennine Escarpment (the Hardraw-Scar Limestone of Wensleydale). All these beds lie above the Knipe-Scar Limestone and the true Melmerby-Scar Limestone; but one or two of the lower limestones are occasionally included in the term Melmerby-Scar Limestone on the maps of the Geological Survey, in such wise

that the upper boundary of the Melmerby-Scar Limestone sometimes does, and sometimes does not coincide with the base of the Upper *Dibunophyllum* Sub-zone. The beds contain a similar fauna throughout these two districts, and much the same assemblage is also met with at Humphrey Head in the Grange District. *Lonsdalia floriformis* and *Cyathophyllum regium* are the most characteristic fossils, together with reefs of *Lithostrotion junceum*, while *Diphyphyllum lateseptatum* is also present in the sub-zone in many places. *Productus giganteus* again is common in the Pennine area, but is rare in the Shap District; and *Dibunophyllum muirheadi* occurs locally in the southern portion of the Shap District.

(*i* 11) The Nodular *Girvanella* Band.

This is one of the most constant horizons in the North of England, and occurs at intervals, from the extreme north of Northumberland to Penyghent. It invariably forms the base of the Upper *Dibunophyllum* Sub-zone, and consists of a few inches of impure nodular limestone. The nodules, which average about an inch in diameter, are not true concretions, but are formed of concentric coats of carbonate of lime deposited round fragments of shells, crinoid-stems, etc. Microscopic sections show that the deposit is probably of organic origin, and is associated with more than one form of algal growth. *Girvanella* tubes occur in many of the nodules, while in others the microscopic structure is obscure. On freshly-broken surfaces the nodules appear as brown spots, and exhibit a porcellanous texture resembling *Solenopora* and other algal growths. On weathered surfaces they stand out in relief, and their concentric structure is clearly visible. In some exposures the nodules are stained by hæmatite. The best exposure of the band occurs on the east side of Humphrey Head in the Grange District, and at Tirell and Wintertarn in the Shap District. In the Pennine District it is again found in the lowest Yoredale limestone, exposed in Scordale Beck and High-Cup Gill.[1]

The *Productus*-cf. *giganteus* Band.—This band has only been met with in the Shap and Pennine Districts: that is to say, where the Yoredale type is developed. It is well exposed on Gathorn Plain, and there forms the highest layers of the Maulds-Meaburn Limestone. This band has also been found at the same horizon in the Pennine escarpment. Where present, it may be taken as the upper limit of the *Lonsdalia-floriformis* Beds.

(*i* 12) The *Saccammina-carteri* Band

is especially well developed in the Shap District, where it occurs in the Little Strickland Limestone and can be traced throughout

[1] Outside the area under description the same band occurs in the Oxford Limestone in Northumberland, and in the first limestone above the massive Lower Scar Limestone above Hunt Pot, Penyghent, and near Ribble Head.

the district, between the Eamont and Great Asby. This species has long been known from the Yoredale beds of Durham and Northumberland, and the horizon at which it occurs in the Shap District appears to agree with its lowest-known occurrence in Northumberland. The index-fossil is associated with *Productus edelburgensis*, *Pr. latissimus*, and *Aulophyllum* cf. *pachyendothecum*. The band is also marked by the absence of *Lonsdalia floriformis* and *Cyathophyllum regium*, characteristic forms in the underlying beds.

The higher Yoredale beds, as stated above, are separated locally as a matter of convenience. They are characterized by the abundance of *Dibunophyllum muirheadi*, which, however, is found also, locally, in the *Lonsdalia* Beds below. This species occurs in great abundance in many of the Upper Yoredale limestones, notably the Great or Main Limestones, and persists into the Botany Beds in the Pennine Area. The division includes all the beds, from the Little Strickland or Tyne-Bottom Limestone to the highest limestone at Botany in the Middleton-in-Teesdale District. In the Shap District the majority of these beds are almost devoid of fossils; but in the Pennine District many of the limestones, such as the 'Great' and 'Four-Fathom,' are highly fossiliferous, and abound in specimens of *Dibunophyllum muirheadi*, *Lonsdalia floriformis*, *Productus giganteus*, *Pr. latissimus*, etc.: many of the shales, and occasionally also the sandstones, are fossiliferous.

(*k* 13) The Botany Beds (*Phillipsastræa* Band).

This band is formed of calcareous shales and limestones, and is about 30 feet thick. It is situated high up in the series of grits and shales coloured as 'Millstone Grit' in the Geological Survey maps. The fauna is of considerable interest, and includes numerous specimens of *Dibunophyllum muirheadi*, together with species of *Productus* and *Spirifer* characteristic of the higher limestones of Derbyshire. It is the highest truly marine fauna met with in the Lower Carboniferous beds of the North-Western Province, and contains thin reefs of *Phillipsastræa radiata*.

(2) The Kirkby Lonsdale or South-Western type.—This type is developed only in the southern portion of the area west of the Craven and Dent Faults. It is exposed in three districts: namely, in the country south of Kirkby Lonsdale; in the neighbourhood of Gleaston and Little Urswick, in the Furness District; and in two small inliers south of Carnforth, in the Arnside District. It differs from the Yoredale type just described by the almost total absence of limestone, except at the base, and by the affinities which many of its fossils exhibit to those of Derbyshire and the 'Knoll-Reef' country south of the Craven Faults. The two inliers of limestone which occur in the Millstone Grit south of Carnforth, although much crushed, contain patches of highly fossiliferous rock. We can best regard them as the western

continuation of the Clitheroe and Gargrave limestone-knolls, brought into their present positions by thrusting.

Lithology.—The base of the zone is composed of dark limestone and calcareous shales, following directly upon the Lower *Dibunophyllum* Sub-zone. These beds are succeeded by shales and massive sandstones, which have been extensively quarried for building-stone. In the Kirkby Lonsdale District they contain only one band of limestone, almost entirely made up of crinoid-fragments and destitute of other fossils. At Hawkfield, in the Furness District, however, this horizon is rather more fossiliferous.

Fauna.—The fauna of the lowest limestones and shales is poor in corals, but rich in brachiopods. On the whole, both in the Kirkby Lonsdale and in the Furness Districts, it is characterized by the large number of brachiopods which are met with in the higher portion of the Derbyshire limestone massif, such as *Productus semireticulatus*, *Pr. latissimus*, etc.

[1] *Girvanella* nodules.

Aulopora sp.
Caninoid *Campophyllum*.
[1] *Cyathophyllum regium* Phill.
Aulophyllum cf. *pachyendothecum* Thomson.
Dibunophyllum muirheadi Nich. & Thomson.
Diphyphyllum lateseptatum M'Coy.
Lithostrotion irregulare (Phill.).
Lithostrotion junceum (Flem.).
Lithostrotion m'coyanum Ed. & H.
Lithostrotion portlocki (Bronn).
Lonsdalia floriformis (Mart.).
Syringopora sp.

Chonetes cf. *compressa* Sibly.
Productus cf. *costatus* Sby.
Productus giganteus Mart.
Productus latissimus Sby.
Productus cf. *longispinus* Sby.
Productus semireticulatus Mart.
Pugnax pugnus (Mart.).
Spirifer bisulcatus Sby.
Spirifer duplicicostus Phill.
Spirifer triangularis Mart.
Spirifer crassus de Kon.=*planicostus* M'Coy.

Edmondia sulcata (Phill.).

III. The Shap and Ravenstonedale Districts. (Type Districts.)

The development in these districts may be taken as typical of the succession in the North-Western Province, for it contains the whole of the northern sequence of the Lower Carboniferous rocks up to the Millstone Grit. The *Michelinia* Zone, however, is here but poorly developed, and the higher beds of the Upper *Dibunophyllum* Zone are almost devoid of fossils. These zones must, therefore, be studied more fully in the Arnside District on the south-west and in the Pennine District on the east respectively.

The districts comprise the Carboniferous area lying between the River Eamont and the Dent Fault. The general strike of the beds is north-north-west and south-south-east; but in the neighbourhood of Orton it sweeps round, and runs more directly east and west, returning again to its original direction in Ravenstonedale. The average dip in the neighbourhood of Shap is between 3° and 4° north-eastwards; but east of Orton, where the strike slews

[1] Not found outside this horizon.

round and the ground is traversed by dip-faults, it is higher and more irregular, averaging about 10° north-north-eastwards.

The districts are included in Sheets 30, 31, 39, and 40, Old Series, of the Geological Survey map, and the Carboniferous rocks have been briefly described in the sheet memoirs on Appleby and Mallerstang by Tiddeman, Goodchild, Dakyns and others. A description of a general traverse, from Wasdale Crag, by way of Shap, to the Valley of the Eden near Appleby, is given by J. S. Bland.[1]

The lowest Carboniferous rocks of this area may conveniently be divided into five lithological divisions. The relation of these to the palæontological subdivisions is expressed in the following table:—

Lithological Divisions.	Palæontological Zones.
(7) The Yoredale Beds. Alternations of sandstones with subordinate shales and impure limestones.	Upper *Dibunophyllum* Subzone.
(6) The Knipe-Scar Limestone. Pure white limestones forming the 'Scars' of the District, passing near Kirkby Stephen into shaly limestones.	Lower *Dibunophyllum* Subzone. *Nematophyllum-minus* Subzone. *Cyrtina-carbonaria* Sub-zone (south of Shap only).
(5) The Orton and Ashfell-Sandstone Series. Red and yellow sandstones, with a few calcareous bands in the south.	*Cyrtina-carbonaria* Sub-zone (north of Shap only). Gastropod Beds (upper portion only in Ravenstonedale). *Michelinia* Zone (north of Orton only).
(4) The Blea-Flatt and Tarn-Sike Limestones. Grey and pink shaly limestones, occurring only between Orton and the Dent Fault. In the north they are merged in the Orton Sandstone.	Gastropod Beds (lower portion). *Michelinia* Zone.
(3) The Shap and Ravenstonedale Dolomite Series. Including porcellanous limestones, algal beds, and shales with ostracods.	*Athyris-glabristria* Zone.
(2) Basement Beds. Red shaly sandstones and conglomerates containing Shap-Granite felspars.	No fossils.
(1) Pinskey Beds. Yellow sandy dolomites and dark mudstones, only found in Ravenstonedale.	*Spirifer-pinskeyensis* Zone.

The faunal zones run approximately parallel to the outcrop of the lithological divisions, but the Orton Sandstone enters

[1] Trans. Manch. Geol. Soc. vol. iv (1862–64) pp. 44–61.

at a progressively earlier period as we approach the northern end of the district: thus cutting out first the Gastropod Beds, then the *Michelinia* Zone, and finally the highest beds of the underlying Shap Dolomites. The upper beds of this sandstone also gradually replace the *Cyrtina-carbonaria* Sub-zone in the same direction. As a result, the overlying *Nematophyllum-minus* Sub-zone rests directly upon the sandstone at the base of Hardendale Nab. Even this sub-zone is almost merged in the sandstone at the northern extremity of the district. At the same time, the thickness of the Orton Sandstone diminishes in the same direction, from about 500 feet under Ashfell Edge to 200 feet or less in the neighbourhood of Shap. The net result may be summarized by stating that the individual beds thin gradually when traced from south to north. This thinning is not due to an overlapping of the higher Carboniferous zones against the Lower Palæozoic land-surface, for the Shap Dolomites continue uninterruptedly as far north as the district extends, but is due to the wedge-like thinning of zone after zone in a northerly direction. This would point to a more rapid deepening towards the southern end of the district, especially during the period when the lower zones were being deposited. It will be best to describe a typical section across the district in the neighbourhood of Shap, which may be supplemented by a description of the beds in Ravenstonedale where some of the zones are more fully developed.

The Shap District.

A general section across the district is shown in the accompanying diagram (Pl. LVI, fig. 1). Starting near Shap Abbey it traverses the *Thysanophyllum* Band, a little to the west of Shap village. The section is then transferred along the strike to the outcrop of the same band in Docker Beck. From here it runs nearly due eastwards through Hardendale Nab to the base of the Upper *Dibunophyllum* Sub-zone on Wickerslack Moor. At this point it is again transferred about 2 miles in a north-westerly direction, along the line of strike, to Wintertarn Quarry. From here onwards it traverses the higher beds of the *Dibunophyllum* Zone, until they disappear under the Permian rocks in the neighbourhood of King's Meaburn.

The *Athyris-glabristria* Zone.

The lowest beds are exposed on the right bank of the River Lowther in the cliff opposite Shap Abbey, while the upper portion of the zone is well seen in Docker Beck, a little to the south of Shap village.

The Basement Beds here consist of some 30 feet of irregularly-bedded shaly sandstone and conglomerate; they contain pebbles of the underlying Ordovician rocks, together with fragments of Shap Granite.

Fig. 1.—*Shap Abbey Cliff:* Solenopora *Sub-zone.*

P. de G. B. photo.

[The figure points to the Lower *Solenopora* Band: the *Proava* Band lies at the top of the cliff.]

Fig. 2.—*Halton Green, Arnside District: Knoll-reef Breccia* (D_2–D_3). *(See p. 515.)*

E. J. G. photo.

The *Solenopora* Sub-zone.—The beds overlying the conglomerate in the Shap-Abbey section consist of 60 feet of compact cement-stones and dun-coloured magnesian limestones with partings of shale (see Pl. XLIV, fig. 1). Under the microscope many of the beds are seen to contain quartz-grains, and to be rich in the remains of foraminifera. The following is a typical percentage analysis [1] of the dun limestones :—

$CaCO_3$	71·13
$MgCO_3$	19·72
FeO, etc.	1·78
Insoluble residue	7·37
Total ...	100·00

The origin of the magnesium carbonate has already been discussed (see pp. 457–458).

The shale-band which occurs about half-way up the cliff is crowded with the remains of bryozoa and the flattened shells of *Athyris glabristria* still bearing their fringe-spines. A *Solenopora* Band occurs in the lowest limestone immediately below the bryozoa-shale, and another similar layer is seen near the top of the cliff. It is interesting to note that the specimens of *Solenopora* show no trace of dolomitization, notwithstanding the fact that the matrix in which they occur is highly dolomitic. Miss K. Burke, B.Sc., of University College (London), to whom I am indebted for analyses of specimens of *Solenopora* from this section, finds that they contain over 99 per cent. of calcium carbonate. This fact would appear to point to the process of dolomitization having been selective, and affords food for speculation regarding the original composition of the thalli constituting these organisms, since among living calcareous algæ some are formed of aragonite and others of calcite. It is possible, however, that the markedly compact character of the *Solenopora* nodules may have enabled them to resist alteration; while the fragments of brachiopods and other organisms have been more readily dolomitized.[2] *Athyris glabristria* occurs abundantly, and forms a band at the top of the cliff. Dr. Vaughan, who has kindly examined specimens from this locality, reports that many of these resemble closely forms from Z_2 of the Bristol District. The general fauna of this sub-zone has already been tabulated (see p. 460).

The *Camarotoechia-proava* Band crops out a few yards back from the top of the cliff; it is poorly developed here, and has not been traced any farther in a northerly direction. To the south-east, however, the zone increases in importance, and in the neighbourhood of Rayne the band is crowded with the index-fossil. At the base of this bed occurs a layer largely made up of plates

[1] For this and other analyses I am indebted to Miss Winifred May, B.Sc., and Mr. M. R. Reid, of University College (London).

[2] The *Girvanella* nodules at the base of the Upper *Dibunophyllum* Sub-zone on the other hand, are frequently much more highly impregnated with hæmatite than the surrounding matrix.

and spines of *Archæocidaris*, together with the plates of *Palæchinus*. This layer has been largely quarried in the neighbourhood of Keld, and slabs from this horizon form a feature of the walls in the neighbourhood; the exposures are, however, now grassed over. Above the *C.-proava* Band occurs a series of dun-coloured magnesian limestones, which are well exposed in the lower portion of Docker Beck, west of the main road; these contain numerous drusy cavities, but have yielded no fossils.

North of Shap the *Solenopora* Sub-zone thins out gradually, and fossils are scarce. To the south-east very few exposures occur at this horizon, until we reach the neighbourhood of Fawcett Mill and Kelleth.

The *Seminula-gregaria* Sub-zone: the *Productus-globosus* Band.

The algal layer lying at the base of the band attains its fullest development in this district. On the line of section it is found cropping out in the field above the Abbey Cliff; but it is better exposed in Docker Beck, at the base of the old quarry beside Force Bridge, 300 yards south of the Greyhound Inn. The general outcrop over the district is shown on the map (Pl. LIII). The most important exposures occur between Chapel Beck and Newbiggin, and include a curious series of thin undulating sheets of limestone apparently representing another form of algal growth.

The main portion of the band is exposed in the Force-Bridge quarry, where it is represented by the hard purple dolomite behind the lime-kiln. The band is not very fossiliferous, but contains the chief forms characteristic of this horizon (tabulated on p. 463), and, in addition, specimens of *Murchisonia marri* and examples of the teeth of *Chomatodus cinctus*.

Farther south, a third of a mile beyond Shap Toll-Bar, occurs an old excavation now grassed over, first pointed out to me by Dr. J. E. Marr. It has yielded a comparatively rich fauna, especially characterized by the large number of gastropods, notably *Murchisonia marri*, for which it is the type-locality. The fossils occur in a pale buff-coloured magnesian limestone, most of the shells being replaced by crystalline calcite. In the upper part of the quarry, this bed is succeeded by a dark dun-coloured rock containing numerous casts of *Syringothyris cuspidata* and *Athyris glabristria*.

Fauna.

Archæosigillaria vanuxemi Göppert.

Athyris glabristria (Phill.).
Seminula gregaria (M'Coy), abundant.
Syringothyris cuspidata (Mart.).

Aviculopecten sp.

Conularia quadrisulcata Sby.
Euomphalus acutus Sby.
Flemingia suturalis (Phill.).
Loxonema acutum de Kon.
Loxonema rugiferum Phill.
Murchisonia marri Donald, abundant.
Naticopsis (*Pileopsis*) *neritoides* (Phill.).
Pleurotomaria (*Ptychomphalus*) *vittata* Phill.

Nautilus biangulatus Sby.
Cycloceras lævigatum M'Coy.
Orthoceras sp.

Leperditia okeni.

This development is somewhat exceptional, the gastropod fauna being unusually rich. When the band next appears near Fawcett Mill, 5½ miles to the south-east, the character of the deposit, as well as its fauna, has resumed the normal development. The rock here consists of a grey compact limestone, containing patches crowded with *Rhynchonella fawcettensis* and *Productus rotundus*, together with a few examples of *Pr. globosus*. Above the *Pr. globosus* Band in Docker Beck the beds are composed of unfossiliferous dun-coloured dolomites which contain occasional 'fucoid' impressions, similar to those found at identically the same horizon at Meathop (Arnside District).

The *Thysanophyllum-pseudovermiculare* Band crops out as a low escarpment in Shap village, between the railway-station and the old Moot Hall. The rock is a compact grey limestone; and the coral occurs in reef-like masses, accompanied by 'fucoid' impressions and early examples of *Productus* cf. *corrugato-hemisphericus*. The outcrop of the band is influenced by the shallow synclinal fold which alters the strike of the beds to the east of Rosgill; it crosses the village of Shap, and runs north-westwards to the neighbourhood of Helton Flecket. Along this line it is exposed in several shallow workings. In Docker Beck this band forms the lower waterfall about 350 yards east of the railway-arch. The rock here contains oolitic layers, with *Bellerophon costatus* and *Seminula gregaria*. Everywhere in the neighbourhood of Shap this band is thin and inconstant, but increases in importance as it is traced in a south-easterly direction. It is well exposed on Birkbeck-Fells Common, in Rais Beck, and on Ravenstonedale Moor. The beds overlying the *Thysanophyllum* Band form the lower waterfall in Docker Beck, and are rich in *Bellerophon*. They are still composed of magnesian limestones, but are, on the whole, more calcareous and show a marked tendency to oolitic structure. Above the lower waterfall, the bed of the stream forms a nearly level reach covered with alluvium.

The Brownber Pebble-Bed is not well seen in Docker Beck, but a good exposure occurs in the railway-cutting east of Shap village, behind St. Michael's Church, where it immediately overlies the *Thysanophyllum* Band. It is here over 20 feet thick, and contains *Syringothyris cuspidata*, *Camarophoria isorhyncha*, and *Athyris glabristria*. The bed is not well exposed between Shap and Orton; but to the east of the latter village it has been extensively quarried on Ravenstonedale Moor, about three-quarters of a mile north of Wath. This is the best exposure of the bed, and its special petrographical characters can be well studied; it is also more fossiliferous here than elsewhere, and the faunal list tabulated on p. 465 is chiefly compiled from this section. Still farther east it is exposed in the type-locality, near Brownber, in a small cutting by the roadside, west of the railway-arch. There are good reasons for supposing that this bed is contemporaneous with similar pebble-beds found at the base of the succession in the Westmorland portion of the Pennine Chain, and that the pebbles

were derived from the quartz-veins which traverse the Lower Palæozoic rocks in the neighbourhood of Brownber Pike in the Cross-Fell Inlier.

The *Spirifer-furcatus* Band forms a thin bed, with a structure resembling oatmeal; it crops out in Docker Beck about 20 yards above the upper waterfall, and just below the ford. The matrix is somewhat oolitic, and the shells are replaced by crystalline calcite. This 'oatmeal bed' may be correlated with the *Spirifer-furcatus* Band of Meathop in the Arnside District.[1]

The *Michelinia* Zone enters in Docker Beck near the base of the Orton Sandstone Series, about 12 feet above the *Sp.-furcatus* Band and about 160 yards up-stream from the upper waterfall. It is represented by a band of oolitic limestone about a foot thick, crowded with the shells of *Camarophoria isorhyncha*. The oolitic coatings have in many cases been deposited round rolled quartz-grains, and the fossils are also rolled and somewhat fragmentary, pointing to a continuation of shallow-water conditions and current-action throughout this period.

Fauna.

Cyathophyllum multilamellatum M'Coy. Abundant.
Michelinia grandis M'Coy.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (M'Coy). Abundant.
Derbya sp.
Productus cf. *corrugato-hemisphericus* Vaughan.
Reticularia lineata (Mart.).
Seminula cf. *ambigua* (Sby.).
Syringothyris cuspidata (Mart.). Rare.

Bellerophon costatus Sby.
Straparollus sp.

Polyrhizodus sp.

As previously mentioned,[2] the rich fauna of the *Michelinia* Zone of the Western Districts is almost unrepresented in the Shap and Pennine Districts. The occurrence of a large example of *Michelinia grandis*, associated with *Camarophoria isorhyncha*, in this section shows that the lower portion of the *Michelinia* Zone is represented here, and that the upper portion of the zone must therefore be merged in the overlying Orton Sandstone. No fossiliferous exposures of the *Michelinia* Zone are observed south of Docker Beck until we reach Ravenstonedale Moor, where small outcrops of this zone occur in two potholes immediately above the quarries opened in the Brownber Pebble-Bed.

Productus corrugato-hemisphericus Zone: The Gastropod Beds.—The exposures of the Orton Sandstone in Docker Beck below Water's Farm call for no special comment, and they yield no fossils beyond obscure casts of lamellibranchs and plant-remains; a thin layer of pebbles, however, recalling the Brownber

[1] See Geol. Mag. dec. 5, vol. vii (1910) p. 118.
[2] *Ibid.* dec. 5, vol. iv (1907) p. 70.

Pebble-Bed, occurs a short distance below the farm. Above Water's Farm a bed of hard calcareous mudstone crops out on the left bank of the stream, and from it the following species have been collected :—

Syringopora cf. *distans* Fischer.
Lithostrotion martini M. Edw.
Zaphrentis enniskilleni M. Edw.

Productus cf. *punctatus* Mart.
Productus cf. *pyxidiformis* de Kon.
Rhipidomella michelini (L'Éveillé).
Seminula ambigua (Sby.).
Spirifer sp.

Allorisma variabilis (M'Coy).
Aviculopecten cf. *interstitialis* Hind.
Crenipecten semicircularis (M'Coy).

This fauna is evidently the attenuated representative of that which characterizes the lower portion of the Gastropod Beds at Blackstone Point in the Arnside District, described later, and shows that this sub-zone (as well as the greater portion of the *Michelinia* Zone) is merged in the Orton Sandstone. South of Docker Beck very few exposures are met with in the sandstone, and these contain only casts of *Stigmaria*. South of Long-Scar Pike, however, a calcareous mudstone occurs, resembling that just described above Water's Farm. As we pass to the south-east of the Shap District, the sandstone episode begins at progressively higher horizons; so that the lower portion of the Gastropod Beds as well as the *Michelinia* Zone eventually crop out as calcareous deposits beneath the sandstone on Ravenstonedale Moor, and in the neighbourhood of Scandal Beck. Above the sandstone the lowest layers of the limestone which underlies the *Cyrtina-carbonaria* Sub-zone on Orton Knott, appear also to belong to this sub-zone; they include bands of lighter-coloured breccia, embedded in a darker, more crystalline, matrix. It seems probable that, in this case, the breccia is due to contemporaneous erosion.

The *Cyrtina-carbonaria* Sub-zone has not been observed in the Docker-Beck section. It appears to be merged in the upper portion of the Orton Sandstone. A short distance to the south, however, it is met with below Long-Scar Pike, and it gradually increases in importance as it is traced eastwards into Ravenstonedale. The lithological characters and organic contents of this sub-zone have already been described (see pp. 470–71).

Localities.—Long-Scar Pike, Orton Knott, Sunbiggin, Severals, and Smardale Gill.

The *Nematophyllum-minus* Sub-zone is comparatively thin in the neighbourhood of Shap; it is exposed near a dried-up pond, about 80 yards west of 'The Nab' Farmhouse, and also near the head of Docker Beck. It is neither so thick nor so well developed as in the Western Districts, and *Chonetes papilionacea* is a rare fossil here, although so abundant at this horizon in the Arnside and Grange Districts. The rock is a grey limestone, weathering white. The sub-zone increases in thickness as it is traced southwards and eastwards into the Ravenstonedale District. The index-fossil occurs somewhat abundantly, and is accompanied by

species of *Syringopora* and *Lithostrotion*. These are usually silicified, and form conspicuous tufts on the weathered surfaces. The general outcrop is shown on the accompanying map (Pl. LIII); a list of the fauna has already been tabulated (p. 473).

The Bryozoa Band crops out on the line of section near 'The Nab' Farmhouse, a few feet above the highest occurrence of *Nematophyllum minus*; it is here about 30 feet thick. The rock is fine-grained, frequently porcellanous, and contains a few thin layers rich in *Calcisphere* and allied forms associated with plant-remains. From 'The Nab' Farmhouse this band can be traced in a north-westerly direction along 'the Edges' to the lime-kiln at Sweetholme, where it is highly fossiliferous, and thence by the base of Knipe Scar to Whale. To the south of Hardendale Nab it is exposed under Long-Scar Pike, and occurs also as an inlier near the head of Lyvennet Beck, where it includes the interesting porcellanous layer containing *Calcisphere* and plant-remains (see Pl. XLVII, fig. 4). At the southern end of the district the band is exposed on Crosby Garret Fell, Weather Hill, and Begin Hill, and in the neighbourhood of Scandal Beck; it is usually much more fossiliferous than the overlying and underlying beds. It reaches its most massive, and in many respects most interesting, development on Orton Knott, where it includes a bed of fine grey and yellow limestone crowded with bryozoa, in particular *Fenestella*, and is further characterized by the abundance of Capulids and the large size of the specimens of *Pterinopecten dumontianus*. The exposure of this band on Crosby Garret Fell closely resembles the Bryozoa Band which occurs at the same horizon in the Pennine District to the east of Roman Fell, both exposures being characterized by the abundance of *Stenopora compacta*.

The Lower *Dibunophyllum* Sub-zone forms the main mass of the Knipe-Scar Limestone throughout the Shap District, and gives rise to the fine series of escarpments which constitute so marked a feature of the country between Askham and Little Asby: notably, Knipe Scar, Hardendale Nab, Long-Scar Pike, and Orton Scar. On the east of the water-parting these beds form the bare dip-slopes in the neighbourhood of Oddendale, Great and Little Asby, and Gathorn Plain. The beds are composed of massive sub-crystalline grey limestones, and include (as usual) a 'spotted' bed near the base, which is well exposed at Trainrigg. Pseudo-breccias are also conspicuous on the surface of the dip-slopes near the summit of the sub-zone, and west of Oddendale they form the limestone-ridges locally known as 'Deadmen's Graves.'

In the neighbourhood of Shap the sub-zone is about 300 feet thick; but it increases in thickness to the south of Hardendale Nab, and on Gathorn Plain cannot be far short of 500 feet thick. A conspicuous feature of the fauna is the abundance and size of the specimens of *Alveolites capillaris*, which occur in subspherical masses measuring as much as 10 inches in diameter.

The *Chonetes*-aff. *comoides* Band is well developed in this district. It lies about 20 feet below the summit of the Lower *Dibunophyllum* Sub-zone, and is well exposed on the line of section at Grandy, close to Oddendale Farm, and elsewhere along the strike, notably on Gathorn Plain.

Fauna.

Nematophyllum (*Lithostrotion*) cf. *minus* M'Coy.
Lithostrotion junceum (Flem.).
Lithostrotion portlocki (Bronn).
Dibunophyllum muirheadi Nich. & Thomson.
Chonetes aff. *comoides* (Sby.).
Daviesiella cf. *llangollensis* (Dav.) (young).
Cyrtina septosa (Phill.).
Productus striatus Fischer.
Productus hemisphericus Sby.
Productus cf. *maximus* M'Coy.

This band is succeeded by about 20 feet of a dark nodular limestone, which is almost devoid of fossils.

The Upper *Dibunophyllum* Sub-zone: The *Lonsdalia* Beds.—In the Shap District the rocks of this sub-zone belong to the Eastern or Yoredale type described above. The massive Knipe-Scar Limestone is everywhere overlain in this district by a thin sandstone which forms the base of the Yoredale Series, and this may conveniently be taken as the base of the Upper *Dibunophyllum* Sub-zone. The three lowest limestones, from the Askham to the Maulds-Meaburn Limestone inclusive, contain *Lonsdalia floriformis*.

On the Geological Survey map the Askham Limestone is correlated with the middle portion of the Melmerby-Scar Limestone of the Pennine escarpment; but, as shown below, the Melmerby-Scar Limestone contains the upper portion of the *Nematophyllum-minus* Sub-zone and the Lower *Dibunophyllum* Sub-zone, and is therefore the equivalent of the Knipe-Scar Limestone of the Shap District.

The Askham Limestone and the beds immediately overlying it are best examined at Wintertarn Quarry, about 2 miles north-west of Oddendale, the point to which the line of section is transferred.

The *Girvanella* Band occurs near the base of Wintertarn Quarry, close to the lime-kiln, the nodules being stained with hæmatite: fossils are scarce, but *Lonsdalia floriformis*, *Chonetes* cf. *compressa* Sibly, and *Pugnax pugnus* occur. A small exposure in the overlying limestone has also yielded specimens of *Lonsdalia*. The same beds may be further examined on Wickerslack Moor, where they contain reefs of *Lithostrotion junceum* at the base and *Cyathophyllum regium* near their summit. Farther north the band forms an outlier on Outscar, where it contains a fairly rich and characteristic fauna. At Thorp, on the extreme northern border of Westmorland, the band is again met with, and the nodules are here also stained by hæmatite.

The *Lonsdalia* Beds are well exposed in the neighbourhood of Haber, west of Crosby Ravensworth; and on Bank Moor,

close to the road from Orton to Appleby, where they contain reefs of *Lithostrotion m'coyanum* and *Cyathophyllum regium*. Farther east good exposures occur at Beccham's Quarry and in Coal-Pit Sike, both of which are characterized by the abundance of *Dibunophyllum muirheadi*; the horizon of these beds may, however, be slightly higher in the Yoredale Series than that of the beds exposed at Outscar and Wintertarn.

The *Productus*-cf. *giganteus* Band.—The highest limestone containing *Lonsdalia floriformis*, which crops out on Bank Moor, is locally known as the Mauld's-Meaburn Limestone; it is characterized in this locality by a great abundance of specimens of *Pr.* cf. *giganteus*,[1] which occur embedded in shale near the summit of the limestone. As this form has not been met with outside the two Eastern Districts, it is thought well to append a list of the chief fossils found associated with it:—

Lithostrotion portlocki (Bronn).
Lithostrotion junceum (Flem.).
Lonsdalia floriformis (Mart.).
Productus cf. *giganteus* Mart.
Productus latissimus Sby.
Productus cf. *edelburgensis* Phill.

The *Saccammina-carteri* Band occurs in the Little Strickland Limestone, which is separated from the preceding band by a somewhat massive sandstone. It is exposed near High Sides on the line of section. Fossils are not abundant, but the following occur:—

Saccammina carteri Brady.
Aulophyllum cf. *pachyendothecum* Thomson.
Diphyphyllum lateseptatum M'Coy.
Lithostrotion junceum (Flem.).
Lithostrotion irregulare (Phill.).
Productus latissimus Sby.
Productus edelburgensis Phill.

Lonsdalia does not, apparently, persist up to this horizon in the Shap District. *Saccammina carteri* occurs abundantly near the top of the bed, recalling the well-known 'Spotted Post' of the Durham quarrymen. This is the only horizon at which I have met with this interesting foraminifer in the North-Western Province, and it has not been previously recorded from Westmorland or Lancashire. In Northumberland and Durham it is especially characteristic of the Acre and Four-Fathom Limestones, although it is occasionally found in the limestone below.

The Little Strickland Limestone of the Shap District corresponds to the Tyne-Bottom Limestone of the Pennine District and, probably, to the Eelwell Limestone of the Lowick district in Northumberland, which lies next below the Acre Limestone. The band can be traced from Little Strickland, by Greenrigg and Bysteads, to Bank Moor; everywhere it is characterized by the abundance of *Saccammina* associated with *Productus edelburgensis*.

The higher beds of the Yoredale Series to the east of Shap call for no special description: they are, as a rule, unfossiliferous, and the limestones are locally dolomitic and frequently stained with hæmatite. Farther south, between Crosby Ravensworth and

[1] This fossil is probably distinct from *Pr. giganteus* Mart., and is practically limited to this horizon in the North-Western Province.

Burrells, the limestones are occasionally fossiliferous, but no examples of *Cyathaxonia*, which is so characteristic of the D_3 beds of the Midland area, have been found, nor any of the forms usually met with at that horizon. The upper limestones are here highly magnesian, and the dolomitized fragments in the Permian Brockrams at Burrells may well have been directly derived from these magnesian limestones.

The Ravenstonedale District.

The rocks in this district form the southern continuation of the Shap sequence.[1] The district includes all the Carboniferous rocks which lie between the North-Eastern Railway and the Dent Fault. The lower beds dip fairly uniformly north-eastwards at about 15°: decreasing somewhat on the east of the water-parting, but increasing again in the neighbourhood of Kirkby Stephen. The total thickness of Carboniferous rocks exposed in the district is between 3000 and 3500 feet. The lowest beds are well seen between the base of the Howgill Fells and Ashfell Edge, while the higher beds form the dip slope between Ashfell Edge and Kirkby Stephen; here, in places, the dip almost coincides with the slope of the ground, so that the *Nematophyllum-minus* Beds, the Bryozoa Band, and the Lower *Dibunophyllum* Sub-zone occupy a considerable extent of country on the east of the water-parting. The highest beds near Kirkby Stephen cannot, however, lie far below the base of the Upper *Dibunophyllum* Sub-zone. The district is traversed by a series of nearly north-and-south faults which, nevertheless, do not affect the general interpretation of the succession. The section (Pl. LVI, fig. 2) gives a general idea of the sequence in this district. The important points to be noted in a comparison of this development with that in the Shap District are:—

(1) The presence of a fossiliferous series of deposits in Pinskey Gill, which underlie the Shap Basement Conglomerate and represent older beds than any found elsewhere in the area, and moreover contain an unique fauna.

(2) The increased thickness and consequent greater importance of the members of the series lying below the Ashfell Sandstone.

(3) The distinctly later period at which the sandstone phase (represented in the north by the Orton Sandstone and in the south by the Ashfell Series) begins in the Ravenstonedale District. Thus the base of the Gastropod Beds in Tarn Sike, close to the Dent Fault, lies about 350 feet below the base of the Ashfell Sandstone; whereas the same horizon at Shap (in the Docker-Beck section above Water's Farm) lies 60 feet above the base of the corresponding Orton Sandstone.

(4) The change in the petrological and palæontological characters of the Lower *Dibunophyllum* Sub-zone, which is here represented by a shaly argillaceous limestone and is characterized by the general absence of Dibunophyllids and *Cyathophyllum murchisoni*, also by the presence, in its upper portion, of reefs of *Lithostrotion junceum* which are elsewhere characteristic of the base of the Upper *Dibunophyllum* Sub-zone.

(5) The absence of the Upper *Dibunophyllum* Sub-zone, due to the overlap of the Permian beds on the Lower *Dibunophyllum* Sub-zone in the neighbourhood of Kirkby Stephen.

[1] Geol. Mag. dec. 5, vol. iv (1907) pp. 70–74.

The Pinskey-Gill Beds.—These beds are named from their occurrence in Pinskey Gill, a mile south of Ravenstonedale Station. They are first seen about 150 yards down stream from the easternmost outcrop of the Bannisdale Slates. The lowest beds consist of a fine-grained, grey and yellow, banded sandstone, about a foot thick, containing conspicuous black specks. Immediately above this sandstone lies a bed of gritty, dun-coloured, calcareous mudstone having the following percentage composition :—

$CaCO_3$	69·96
$MgCO_3$	8·84
Fe_2O_3, etc.	4·47
Insoluble residue	16·73
Total	100·00

The bed shows little or no trace of lamination, and breaks into small irregular blocks. Occasionally, it encloses thin lenticular pebbles measuring up to 2 inches in diameter, composed of a finer material which resembles a volcanic ash : these pebbles are frequently coated with a thick layer of pyrite. A few small quartz-pebbles also occur. The bulk of the insoluble material is composed of sand-grains, and although search has been made for fragments of Shap-Granite felspar-crystals, which occur so abundantly in the overlying conglomerate, no trace of these has been discovered. The bed has yielded fossils in fair abundance, but only in the form of casts—with the exception of specimens of *Lingula* and *Orbiculoidea*, in which the shell is still preserved.

Fauna.

Fenestella sp.

Lingula cf. *squamiformis* Phill.
Orbiculoidea sp.
Athyris, between *glabristria* (Phill.) and *concentrica* Von Buch.

Rhynchonella sp.
Spirifer pinskeyensis, sp. nov.

Psephodus sp.[1]

This sandstone is overlain by dark sandy shales, which have only yielded casts of lamellibranchs.

Farther down the stream higher beds are exposed, consisting of compact mudstones interstratified with shales. These have yielded the following fossils :—

Lingula cf. *squamiformis* Phill.

Aviculopecten, 2 spp.
(?) Myalina sp.

Posidoniella sp.

Naticopsis sp.

Psephodus sp.[1]

On the right bank a small cliff-section exposes flaggy and shaly beds, containing worm-tracks and plant-remains which are referable

[1] Kindly determined by Dr. A. Smith Woodward, F.R.S.

to *Pteridorhachis* sp.[1] Above the plant-shales occurs a yellow cellular dolomite containing drusy cavities. This is the highest bed in the series exposed in the bed of the stream, but it has yielded no determinable fossils. The total thickness seen is about 65 feet, and the beds are dipping at 17° north-north-eastwards, or about the same average dip as that of the overlying Lower Carboniferous rocks in the district.[2]

About 8 yards below the road-bridge is a small outcrop of thinly-bedded, red, shaly conglomerate, which contains pebbles ranging up to 2 inches in diameter and composed of Silurian grits and rhyolites; also scattered through the deposit are pink orthoclase-crystals, similar to those commonly found in the conglomerate at Shap Wells, and there can be little doubt that this deposit is the southerly continuation of the Shap Basement Conglomerate. The beds in Pinskey Gill, described above, are therefore of peculiar interest, since they apparently underlie the Shap Conglomerate which forms the usual base of the Carboniferous in the Shap District, and must therefore represent the oldest fossiliferous horizon in the Carboniferous rocks of the North-Western Province. The beds were evidently deposited in a depression which was invaded by the Carboniferous sea before the general submergence of the districts lying immediately to the north and south, and apparently prior also to the submergence of the Shap Granite. How much earlier it is impossible to say, by comparison with any beds in the North of England—since the nearest exposures of Carboniferous rocks, which may possibly represent their equivalents in time, are not met with until we reach the extreme north of Cumberland; and my recent investigation of the beds in this district has revealed no fauna at all similar to that recorded from Pinskey Gill. Again, if these beds are of Carboniferous age, it should be possible to correlate them with some definite horizon in the Lower Carboniferous succession of the South-Western Province, but such a correlation is by no means easy.

If we are to consider the Pinskey Beds as conformably succeeded by the conglomerate which crops out below the bridge, and by the fossiliferous series exposed in Stone Gill hard by, they should represent some portion of the *Zaphrentis* Zone of the Bristol district; but Dr. Vaughan, who has kindly examined my collections, and also specimens collected by Mr. Cosmo Johns from this district, reports that the characteristic *Spirifer* of the Pinskey Beds is quite unknown to him from the Carboniferous rocks of the Bristol area, while none of the other fossils appear to throw any further light on the problem.

Considered on stratigraphical grounds alone, these beds may be of any age between the date of the post-Silurian movement in the district, and the deposition of the lowest beds of the *Solenopora* Sub-zone: that is to say, there is apparently nothing in the strati-

[1] *Teste* Prof. A. C. Seward, F.R.S.

[2] A detailed section of these beds is given in 'The Geology of the Country around Mallerstang, &c.' Mem. Geol. Surv. 1891, p. 79.

graphical evidence to prove that the deposit is not of late Devonian age. On the other hand, no marine deposits of Devonian age are known in the North of England, while the Polygenetic Conglomerate, which occurs north of Bampton and in the neighbourhood of Sedbergh and elsewhere, has been considered by some authorities as a torrential deposit of Upper Devonian age. This conglomerate is certainly older than the beds which form the usual base to the Carboniferous in the North-Western Province, and its sporadic distribution would seem to point to extensive denudation in pre-Carboniferous times. No definite evidence can, however, be deduced from a study of the fauna of the Pinskey Beds in favour of the Devonian, any more than of the Carboniferous age of the deposit. In this connexion the statement, made in the Geological Survey Memoir on Mallerstang, &c., that one of the beds contains *Producti* is important: for, though *Productella* does occur in the Devonian beds of North Devon, the occurrence of true *Producti* at Pinskey would settle the question in favour of the Carboniferous age of the beds. I have not, however, met with any specimen of *Productus* in these beds; and a search among the collections and records of the Geological Survey at Jermyn Street has also failed to produce any corroboration of the statement contained in the Memoir. Under these circumstances the record of the occurrence of *Productus* in these beds must be regarded as unsupported.

Summary.—We have, then, in Pinskey Gill a series of fossiliferous deposits which are of considerable interest, on account of their unique character and their uncertain age. The facts, so far as they have been ascertained, may be summarized as follows:—

(1) The beds lie apparently between the Silurian rocks and the basement Carboniferous conglomerate of the district.
(2) Their relation to the underlying Silurian slates and overlying Carboniferous conglomerate is obscured by drift, but the dip of the beds does not differ appreciably from that of the overlying Carboniferous rocks.
(3) They are undoubtedly older than any Lower Carboniferous beds so far met with elsewhere in the North-Western Province.
(4) Their lithological and palæontological characters differ markedly from those of the overlying beds.
(5) They are entirely devoid of fragments of the Shap-Granite felspars, which are so characteristic of the basement-beds in this district and occur abundantly in the overlying conglomerate.
(6) The fossils, with the exception of inarticulate brachiopods, are preserved as casts, whereas the organic remains in the beds overlying the conglomerate have their tests well preserved.
(7) The fauna is difficult to correlate with that from any known horizon in the Lower Carboniferous succession of the South-Western Province.

[Since the above was written, I have again visited the section in Pinskey Gill, in the company of Mr. R. G. Carruthers, on which occasion some additional fragments of fish-teeth were obtained. Dr. A. Smith Woodward, who has kindly examined these specimens, reports that they represent a Cochliodont of some kind, probably *Psephodus*, and, so far as they go, therefore, point to the Carboniferous age of the deposit.]

Despite careful search, no other undoubted occurrence of the Pinskey-Gill Beds has been met with. A few feet of unfossiliferous

dolomite and mudstone are, however, exposed in Weasdale Beck, along the same line of strike; while below Shaw Mire in Thackthwaite Gill, shales, gritty mudstone, and dolomite are exposed: these have, however, yielded no organic remains, and the same remark applies to the lowest beds exposed in Artlegarth Beck.

The *Solenopora* Sub-zone.—The fossiliferous beds overlying the basement Carboniferous conglomerate are best studied in the series of gills which rise on the northern slopes of the Howgill Fells between Pinskey Gill and the Dent Fault. The general character of the succession is shown in the section (Pl. LVI, fig. 2). The best exposures of the lower beds are seen in Stone Gill and Artlegarth Beck. In Stone Gill some 80 feet of dolomites and calcareous shales crop out about a third of a mile above Colbeck Bridge. Unfortunately the lowest beds, including the basement conglomerate, are not exposed here.

Section in Stone Gill.

	Thickness in feet	*inches.*
Porcellanous limestone with *Camarotœchia proava*—		
Black shale	4	0
Massive limestone with shaly partings	14	0
Black shales with *Orthoceras*	4	0
Hard, compact, grey limestones with geodes	3	6
Black shales with plates of *Archæocidaris*	2	0
Earthy limestone	1	0
Shale-band	2	0
Solenopora Band	2	0
Drift-covered (unseen)	5	0
Hard dolomite and shaly calcareous flags	7	0
Palæchinus Limestone, with *Zaphrentis omaliusi* and *Cidaris* spines	1	6
Fragmental bed	4	0
Shaly dolomite	7	6
Dolomite with *Vaughania cleistoporoides*	9	0
Hard, dun-coloured, shaly limestone	6	0
Platy shale with *Athyris glabristria*, ostracods, etc.	3	3
Hard blue limestone with *Syringopora* and *Hyalostelia*	3	0

Base not seen.

These beds represent approximately the same horizon as those exposed in Shap-Abbey Cliff already described (p. 487). The beds, as in the case of the Shap section, contain abundant remains of *Solenopora*: one layer, 45 feet from the base, being almost entirely composed of the thalli of these organisms. The abundance of *Athyris glabristria* in the lowest shale-bed, near the base of the section, recalls a similar layer near the top of Shap-Abbey Cliff; while the presence of a bed composed almost entirely of the plates of *Palæchinus* and *Archæocidaris* corresponds with the *Archæocidaris* Bed north of Keld. The interesting band containing *Vaughania cleistoporoides* has only been met with elsewhere in the Shap section, and there the coral-remains are very scarce and fragmentary. The fauna from these beds is tabulated in the general list on p. 460.

The *Camarotœchia-proava* Band attains its maximum development in Stone Gill, where it cannot be far short of 700 feet in thickness, and consists of a compact porcellanous limestone containing layers crowded with the index-fossil. Another good exposure of this band occurs near Piper Hole in the line of section, where it is underlain by the *Palæchinus* Limestone, which in turn overlies a black calcareous shale containing *Modiola*, etc.

The *Seminula-gregaria* Sub-zone. — The *Productus-globosus* Band, with the algal layer at its base, enters the district at Friar Bottom immediately east of the railway. It crops out at intervals between here and the Dent Fault. An interesting exposure at about this horizon occurs in a small quarry on the north side of the road between Ravenstonedale and Claylands. Here a red calcareous shale is seen crowded with specimens of *Stenophragma lobatum* Munro, apparently a new form of Trepostomatous Bryozoa, of an irregularly lobate habit.[1] Examples also occur of an interesting compound coral, which shows affinities both with *Thysanophyllum* and with *Lonsdalia*.[2]

A good section, showing the relation of the band to the overlying *Thysanophyllum* Band, is seen opposite Brunt-Hill Farm, where about 80 feet of fossiliferous shales and limestones are exposed. Fossils obtained from this section are included in the general list (p. 463).

The *Thysanophyllum* Band is well developed in this district; its outcrop is shown on the map (Pl. LIII).

Localities. — Cowpland Sike, Breakyneck Scar, Blea-Flatt Spinney, and near Brunt Hill. The exposure in Cowpland Sike is remarkable for the abundance of well-grown specimens of *Fistulipora incrustans*.

The Brownber Pebble-Bed, exposed at the type-locality west of the railway, crops out again above the *Thysanophyllum* Band on the west side of Scandal Beck, but it is only seen in two small exposures at the eastern end of the district: one at a point a little north-east of Claylands Farm, and the other in Tarn Sike, east of Crooks Beck. In both of these places it appears to be thinning out southwards.

The *Michelinia* Zone is better developed and better exposed here than in the Shap District; it is, however, difficult to say what thickness of beds should be included in the *Chonetes-carinata* Sub-zone of the Arnside District. *Michelinia grandis* has been collected in an old quarry by the roadside immediately opposite Blea-Flatt Farm, and again at one or two points between Keld Sike and Ashfell Farm. The beds are shaly impure limestones, often stained red, and the fossils are usually silicified; specimens of a small form of *Productus corrugato-hemisphericus* abound, and these are

[1] Described in Appendix II, pp. 574–76.

[2] Pending the thorough revision of this group, the description of this form has been deferred.

associated with a large Diphyphylloid *Lithostrotion* resembling the species found at Blackstone Point. The *Michelinia* is the large form of *Michelinia grandis* characteristic of the base of the zone in the Furness and Grange Districts. A few feet of fossiliferous beds, apparently lying near the summit of the zone, crop out in Tarn Sike; and here *Caninia cylindrica* is associated with early specimens of *Lithostrotion martini*. One specimen of *Clisiophyllum multiseptatum* has also been collected from this exposure. The conclusion, therefore, must be drawn, either that *Michelinia* did not enter this district until the end of the period during which the *Michelinia* Beds were being deposited at Arnside; or that the Diphyphylloid *Lithostrotion* fauna entered here somewhat earlier than in the Arnside District. The latter view is adopted here, chiefly for convenience in mapping, and these beds are therefore represented in the map and section of the district as belonging to the *Michelinia* Zone (Pl. LIII & Pl. LVI, fig. 2).

The following species have been collected from the exposures mentioned above:—

Caninia cylindrica (Scouler).
Clisiophyllum multiseptatum, sp. nov.
Cyathophyllum multilamellatum M'Coy.
Diphyphyllum aff. *lateseptatum* M'Coy.
Lithostrotion martini M.-Edw.
Lophophyllum sp.
Michelinia grandis M'Coy.
Syringopora geniculata Phill.
Chonetes carinata, sp. nov.; rare.
Productus hemisphericus Sby.
Productus corrugato-hemisphericus Vaughan; early form.
Martinia cf. *ovalis* (Phill.).
Schizostoma catillus (Phill.).

The *Productus-corrugato-hemisphericus* Zone: the Gastropod Beds. — As already pointed out, a considerable thickness of calcareous rocks referable to this sub-zone occurs below the Ashfell Sandstone in this district, and passes downwards into the *Michelinia* Bed of Keld Sike. The sub-zone includes the whole of the Ashfell-Sandstone Series, and also probably a few feet of the overlying grey platy limestones, which immediately underlie the *Cyrtina-carbonaria* Beds of Ashfell Edge. At the western end of the district near Scandal Beck, below Gallows Hill, the highest layers of limestone yield numerous casts of *Bellerophon* and masses of *Alveolites etheridgi*. The Ashfell Sandstone contains two or three calcareous layers, the most interesting of which occurs near the top of the sandstone, and is well exposed in the old quarries (north of the road) a little below the summit of Ashfell Edge. Here several species of corals and brachiopods occur in a good state of preservation. The fossils are quite unsilicified, in marked contrast with those which occur in the overlying *Cyrtina-carbonaria* Sub-zone. This calcareous layer is covered by a thin layer of reddish marl, which may have served to protect the fossils from solution or silicification. The fauna is, on the whole, that which is characteristic of the Gastropod Beds elsewhere; but it includes also two rolled specimens of *Camarophoria isorhyncha*, and a fragment of *Syringothyris cuspidata*. *Zaphrentis enniskilleni* enters here at a somewhat higher horizon than at Shap, and in addition

to the typical form at least two variants occur. A new species of *Lophophyllum* (*L. ashfellense*) found here is of interest: it was provided with strong roots, which seem to have been attached in several cases to specimens of *Lithostrotion martini*. The most abundant fossils are, however, *Spiriferina laminosa* and *Seminula ambigua*.

Fauna.

Alveolites etheridgi Thomson.
Lophophyllum ashfellense, sp. nov.
Lithostrotion martini M.-Ed.
Zaphrentis emiskilleni M.-Ed. & variants.

Spirorbis sp.

Cliothyris cf. *royssi* (L'Éveillé).
Camarophoria isorhyncha (Sby.). (Derived.)
Productus corrugato-hemisphericus Vaughan.
Productus hemisphericus Sby.
Productus laciniatus M'Coy.
Productus pustulosus Phill.
Productus cf. *punctatus* Sby.
Reticularia sp.

Pugnax pleurodon (Phill.).
Seminula ambigua (Sby.); abundant.
Spirifer cf. *bisulcatus* Sby.
Spiriferina laminosa (M'Coy); abundant.

Aviculopecten cf. *dissimilis* (Flem.).
Conocardium aliforme Sby.
Edmondia sp.
Sanguinolites sp.

Naticopsis sp.
Pleurotomaria sp.

Produs sp. (?).
Psephodus magnus M'Coy.
Streblodus cf. *oblongus* Portl.

The fauna, as a whole, is of shallow-water character, and appears to result from a slight falling-off in the deposition of arenaceous material.

The *Cyrtina-carbonaria* Sub-zone.—The lowest rocks overlying the Ashfell Sandstone consist of a few feet of compact grey limestone, poor in fossils. They contain, however, masses of *Lithostrotion martini* in the position of growth, together with a few specimens of *Cyrtina* near their summit. They pass up into rather more flaggy limestones, which are often crowded with fossils, especially *Cyrtina carbonaria* and *Syringopora geniculata*, together with an abundance of small gastropods. The fossils are frequently replaced by beekite. This sub-zone is better exposed along the summit of Ashfell Edge than elsewhere in Westmorland. The fauna has already been tabulated on p. 471.

The *Nematophyllum-minus* Sub-zone consists of the usual grey platy limestones. It occupies a considerable stretch of country on the dip side of the escarpment on Ash Fell, where several good exposures occur. The fauna is in no respect different from that which occurs in the Shap District, and there is the same absence of the shaly *Chonetes-papilionacea* Beds which are so characteristic of the upper portion of this sub-zone in the districts on the west.

The Bryozoa Band is especially well-developed on Ash Fell, and is exposed in Blue Quarries on the north side of the road.

The band is much more argillaceous than is the case at Orton and Shap, and consists of dark calcareous shale crowded with bryozoa and *Spiriferina laminosa*.

Localities.—Blue Quarries, Smardale Fell, Ash Fell.

The Lower *Dibunophyllum* Sub-zone is not very typically developed in this district. The base of the sub-zone is exposed in Lane-Head Quarries. This horizon cannot lie far above the highest bed seen in Blue Quarries. The beds here are rolling, and it is difficult to estimate the exact thickness of the strata which overlie the Bryozoa Band between Blue Quarries and the Midland Railway Station. They differ both lithologically and palæontologically from their normal development elsewhere, being much more argillaceous than in the Shap District. No specimens of either *Cyathophyllum murchisoni* or *Dibunophyllum* have been met with; but the abundance of crushed specimens of *Productus* cf. *maximus* (M'Coy) and caninoid Campophyllids seems to point to the correlation of these beds with the Lower *Dibunophyllum* Sub-zone elsewhere. The matter in itself is of no consequence, for we may regard them as passage-beds between the two zones; but it becomes important when we consider the position of the overlying *Daviesiella-llangollensis* Band, to be mentioned presently. In Lane-Head Quarries, on the west side of the Sedbergh road, the beds are fairly fossiliferous, and contain abundant examples of the *Producti* and crushed corals mentioned above, together with large Orthocerata which are unknown from any other horizon in the district. Species of *Syringopora* and *Alveolites* are also common.

Localities.—Lane-Head Quarries; Waitby Common.

Fauna.

Alveolites capillaris (Phill.).
Alveolites etheridgi Thomson.
Aulopora sp.
(?) Caninia.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum ϕ Vaughan.
Lithostrotion junceum (Flem.).
Lithostrotion martini M.-Edw.
Syringopora geniculata Phill.
Syringopora ramulosa Goldf.

Chonetes papilionacea Phill.
Cyrtina carbonaria (M'Coy).
Orthotetes sp.

Productus corrugato-hemisphericus Vaughan.
Productus cf. *maximus* M'Coy.
Productus punctatus Mart.
Reticularia sp.
Seminula ambigua (Sby.).
Spirifer bisulcatus Sby.

Sanguinolites sp.

Straparollus sp.
Bellerophon scalifer de Kon.
Bellerophon sp.

Poterioceras cf. *cordiforme* Sby.

The presence of *Cyrtina carbonaria* in the Lane-Head quarry on the east side of the road marks the highest horizon at which this species has been found, as these beds certainly lie above the Bryozoa Band, whether we consider them as belonging to the base of the Lower *Dibunophyllum* Sub-zone or to the summit of the *Productus-corrugato-hemisphericus* Zone.

The *Daviesiella-llangollensis* Band.—No good exposures occur in the line of section to the east of Lane-Head Quarries, until we pass the Midland Railway-station; but, immediately east of the railway, several good outcrops of an impure shaly limestone can be seen between the station and Wharton Hall: these abound in specimens of *D. llangollensis*, together with *Productus* cf. *maximus*. This band is of especial interest since, with the exception of the young and doubtful examples occurring in the *Chonetes*-aff. *comoides* Band at Grandy, this species has not been met with in the North-Western Province. As at Llangollen, the band appears to lie near the base of the Lower *Dibunophyllum* Sub-zone.

Above the *D.-llangollensis* Band the beds resemble the typical white limestones of the Lower *Dibunophyllum* Sub-zone of other districts; they are, however, cherty and somewhat barren of fossils, and neither *Cyathophyllum murchisoni* nor *Dibunophyllum* occur. The highest exposures contain reefs of *Lithostrotion junceum*, which elsewhere is more characteristic of the base of the Upper *Dibunophyllum* Sub-zone. On the whole, then, the Lower *Dibunophyllum* Sub-zone in the Ravenstonedale District is characterized by its shaly and cherty character, by the absence of *Dibunophyllum* and *Cyathophyllum murchisoni*, and by the presence of the *Daviesiella-llangollensis* Band near its base.

No beds of Upper *Dibunophyllum* age occur in the Ravenstonedale section.

IV. The Arnside and Carnforth Districts.

The Arnside District.

This district may be conveniently considered under the following heads:—(1) A western portion, comprising a considerable area to the south of the Kent estuary and west of the Furness Railway, and also the small outlier of Meathop lying on the north side of the estuary. (2) An eastern portion, lying wholly to the south of the Kent estuary and east of the Furness Railway, treated separately on account of the tectonic disturbances. (3) The faulted inliers of Swantley and Halton Green, lying on the southern margin of the district.

In comparing this district with the type-districts, we may note:—

1. The absence of the greater portion of the *Solenopora* Sub-zone, which is only represented at Meathop by a few feet at the summit of the *Camarotœchia-proava* Band, a fact which shows that this district was submerged at a slightly later period than the type-districts.
2. The development of a special coral fauna in the *Seminula-gregaria* Sub-zone at Meathop.
3. The great importance of the upper portion of the *Michelinia* Zone, which at Arnside attains its fullest development in the North-Western Province.
4. The great thickness of the middle and upper portions of the *Cyrtina-carbonaria* Sub-zone and the Bryozoa Band of the type-districts: the latter being apparently replaced by the *Chonetes-papilionacea* Beds which occur near the summit.

5. The abundance of specimens of *Cyrtina septosa* in the *Chonetes*-aff. *comoides* Band, which here far outnumber the chief index-fossil of the type-districts.

6. The evidence of important tectonic disturbances, especially in the eastern portion of the district, by which the beds are so thrust and tilted that the zones are, in places, inverted.

7. The presence of isolated inliers of limestone among the rocks of the Millstone Grit Series on the southern margin of the district, which exhibit lithological and palæontological characters unknown at any horizon in the type-districts, and in their faunal and structural peculiarities recall the brecciated limestones of the knoll-reef country on the south-east, of which they appear to be fragmentary continuations, brought into their present position by thrusting.

(1) The Western Portion of the Arnside District.

Athyris-glabristria Zone: the Meathop Outlier.—The lowest beds are exposed on the north side of the Kent estuary at Low Meathop, in a small quarry on the east side of the lane leading down to the farm. The actual junction with the Silurian is not seen, but the latter crops out in a field hard by. The exposure consists of a few feet of very tough blue limestone, overlain by unfossiliferous earthy shales. The limestone contains one or two layers crowded with the remains of *Camarotœchia proava*, associated with the following species:—

Solenopora, sp. nov.

Carcinophyllum, sp. nov.
Lophophyllum meathopense, sp. nov.

Athyris glabristria (Phill.).
Camarotœchia proava (Phill.).
Rhynchotreta angulata (Linn.). A large form.
Seminula aff. *ficoidea* (Vaughan).

Modiola cf. *lata* Portl.
Myalina sp.

The form of *Seminula* found here and in the overlying beds east of the road is a large inflated form, difficult to distinguish from *S. ficoides* (Vaughan) of the Bristol *Seminula* Zone.[1] The association of *Solenopora* with *Camarotœchia proava* and *Athyris glabristria* in this exposure points clearly to the horizon being that of the *C.-proava* Band of the Shap-Abbey and Stone-Gill sections already described.

The *Seminula-gregaria* Sub-zone is well exposed in a succession of old quarries between the railway and the road to the east of the gas-works; the total thickness to the top of the cliff is about 140 feet. The beds consist chiefly of compact limestones and dolomites, some of the latter containing up to 30 per cent. of magnesium carbonate.

The Algal Layer.—The layers near the base of the Meathop section are largely made up of the remains of calcareous algæ, which occur on weathered surfaces as grey concretionary spots and nodules

[1] See Pl. LI, fig. 6; also A. Vaughan, Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 122.

embedded in a yellow dolomitic matrix. These layers contain forms identical with those found in the algal layer lying at the base of the *Productus-globosus* Band in the Shap and Ravenstonedale Districts, and undoubtedly represent the same horizon. About 30 feet above the base occurs a compact, porcellanous, grey limestone, containing crushed and recrystallized crinoid-stems, together with teased-out corallites of *Syringopora*. In the succeeding 40 or 50 feet fossils are scarce, with the exception of *Seminula* aff. *ficoidea* and *S. gregaria*. One or two thin black shaly layers, however, occur containing plant-remains, among which fragments referable to *Archæosigillaria vanuxemi* Göppert may be recognized.[1]

In the upper portion of the cliff, silicified fragments of a small *Cyrtina* (aff. *carbonaria*) occur; these are in too fragmentary a condition for exact determination, but the form is not unfrequently met with at this horizon in the Western Districts. The *Thysanophyllum-pseudovermiculare* Band has almost died out here, though one or two corallites, referable to this species, have been collected about 40 feet below the summit of the section.[2] About 30 feet below the top of the cliff the beds become rather more fossiliferous, and in addition to *Seminula* at least two species of *Syringopora* occur in some profusion.

The following species have been collected from the *Seminula-gregaria* Sub-zone at Meathop, up to the base of the *Spirifer-furcatus* Band:—

Archæosigillaria vanuxemi (Göppert).
Fucoid markings.
Calcareous algæ.

Campophyllum ciliatum, sp. nov.
Carcinophyllum simplex, sp. nov. and variant.
Clisiophyllum aff. *curkeenense* (Vaughan).
Carruthersella compacta, gen. et sp. nov.
Lophophyllum meathopense, sp. nov.
Lophophyllum vesiculosum, sp. nov.
Syringopora cf. *reticulata* Goldf.
Syringopora cf. *geniculata* Phill.
Thysanophyllum or *Lonsdalia*.

Athyris glabristria (Phill.).
Athyris cf. *lamellosa* L'Éveillé.
Camarophoria isorhyncha (M'Coy). Rare.
Cyrtina aff. *carbonaria* (M'Coy).
Seminula aff. *ficoidea* Vaughan.
Seminula gregaria (M'Coy).

This assemblage, although containing several new species, agrees with the fauna of the *Seminula-gregaria* Sub-zone of the Shap District, while the Algal Layer, which is so well developed along the bottom of the cliff, may be taken, here as elsewhere, to represent the base of the sub-zone. The Brownber Pebble-Bed has entirely thinned out here, and the *Thysanophyllum* Band is scarcely represented; but the dolomitic character of the rock and the abundance of *S. gregaria* and *S.* aff. *ficoidea*, taken together with the fact that the beds are underlain by the *Camarotœchia-proava* Band and overlain by the *Spirifer*-cf. *furcatus* Band, leaves no

[1] These have also been collected by Mr. J. Wilfrid Jackson, who has in addition identified fragments of *Bothrodendron*, Geol. Mag. dec. 5, vol. vii (1910) p. 78.

[2] These may possibly be identical with the form met with at the same horizon in Ravenstonedale, mentioned on p. 500.

doubt that these beds may be correctly correlated with the *Seminula-gregaria* Sub-zone of the type-districts. The new forms of cup-corals included in the foregoing list, though occasionally met with at the same horizon in other portions of the Western Districts, occur here in much greater abundance than elsewhere. The occurrence of a few specimens of *Camarophoria isorhyncha* below the *Spirifer-furcatus* Band on the east side of the outlier, is of interest, since the horizon coincides with that at which this species is first met with in the Shap District, namely the Brownber Pebble-Bed.

The *Spirifer-furcatus* Band lies at the top of the quarries, and the fossils which it contains are somewhat rolled and fragmentary. The fauna has been tabulated above (p. 465), and, as already pointed out,[1] resembles very closely that of the Oatmeal Bed near the summit of the *Athyris-glabristria* Zone in the Docker-Beck section at Shap. The bed forms the surface of the ground at the southern end of Meathop Fell, and dips at about 5° south-eastwards (that is, towards Arnside). At Meathop-Marsh Farm, on the south-eastern side of the outlier, the beds are more bituminous, and include a thin parting of black shale crowded with the remains of *Lophophyllum meathopense*. East of the quarry this shale-band disappears under the alluvium of the Kent estuary, and has not been met with in the quarry-sections on the west.

The *Michelinia* Zone: its lowest portion, the *Camarophoria-isorhyncha* Sub-zone, is present in the Meathop outlier, and, with the possible exception of a small block of fault-breccia which comes to the surface in Arnside Moss, no other exposure of this sub-zone is met with in the Arnside District. The base of the zone on Meathop Fell appears to lie immediately above the *Spirifer-furcatus* Band at the southern end of the Fell, and this corresponds with its position in the Docker-Beck section at Shap, where it overlies the Oatmeal Bed. The beds consist of a grey and purple, somewhat bituminous limestone containing *C. isorhyncha* and *Cyathophyllum* cf. *multilamellatum*, overlain by a compact dolomite which forms the top of the Fell (172 feet), and can be traced round to the summit of Meathop-Marsh Quarry. No specimen of *Michelinia* has been obtained *in situ* on Meathop Fell, but the walls encircling the western end of Limegarth Wood and the southern edge of the Fell contain numerous specimens of that large form of *M. grandis* which is characteristic of the sub-zone in Docker Beck, Elliscales and elsewhere. Examples of *C. isorhyncha* and *Zaphrentis koninckı* also occur associated with *Michelinia* in these blocks. The blocks evidently once formed portions of the dip-slope at the top of the Fell, and this supposition is confirmed by the statement of the present tenant, who informed the writer that the above-mentioned walls were made from the rocks cropping out on the surface of the Fell.

[1] Geol. Mag. dec. 5, vol. vii (1910) p. 118.

The relation of the rocks of the Meathop outlier to the *Michelinia* Beds at Arnside is naturally to some extent problematical, but there appears to be no good reason why the two exposures should not form portions of a continuous sequence separated by the Kent estuary, since beds containing *Michelinia*, identical with the highest Meathop beds, occur immediately below the shales of the *Chonetes-carinata* Sub-zone at Frith Hall, Elliscales. The main north-and-south fault which runs through Lindale continues southwards into Morecambe Bay, passing between Holme Island and Meathop Fell, and brings the beds, near the top of the Lower *Dibunophyllum* Sub-zone, on the island, against the beds of the *Athyris-glabristria* Zone of the Meathop section. It is exactly here that Morecambe Bay ends and the narrow estuaries of the Kent and the Gilpin begin. There is no evidence of an east-and-west fault in the Kent estuary, though the Gilpin-estuary fault is probably continuous with the Arnside-Carnforth disturbance which runs past Silverdale Station. Again, the dip of the Meathop beds on the south side is the same, in direction and amount, as that of the beds which crop out on the Arnside shore a mile away.

The *Chonetes-carinata* Sub-zone is admirably exposed along the shore between Arnside and Blackstone Point. The rocks here consist of dark-grey, somewhat nodular, bituminous limestones, with partings of shaly calcareous mudstone. The strike of the beds coincides generally with the trend of the coast-line, and the different layers of the sub-zone are exposed at short intervals in a series of anticlines and domes. The best exposures occur in the cliff between Mr. Crossfield's boat-house and the Corporation bathing-shed, but fossiliferous outcrops also occur at intervals along the foreshore between the Crown Hotel and New Barns Farm.

In the cliff near the boat-house the beds are compressed into a sharp synclinal fold, the eastern limb of which is replaced by a fault: several small dislocations also occur farther east, produced by a series of overthrusts from the west; while a fault runs along the foot of the cliff, the beds in its neighbourhood being traversed by calcite-veins. These beds must lie near the top of the zone, for the first Diphyphylloid *Lithostrotion* is met with here, in the synclinal fold, about 25 feet above the beach. This coral is again found abundantly at Blackstone Point, and resembles very closely a form occurring at about the same horizon in Tarn Sikes (Ravenstonedale). The bed in which it is found may be conveniently taken as the base of the *Productus-corrugato-hemisphericus* Zone. A little farther west, a vertical fault plastered with breccia-fragments passes through the face of the old quarry. West of the bathing-shed lower beds are exposed, including several layers of a shaly mudstone which abounds in specimens of *Michelinia grandis* and *M. tenuisepta*. M'Coy's type-specimen of *M. grandis*, from these beds at Arnside, has for many years been referred to *M. megastoma* of Phillips; and the type-specimen is so labelled in the Sedgwick Museum, on the supposition that it was a synonym for Phillips's species. Pending the revision of the species of this genus, M'Coy's

name for the Arnside form is retained here, so as to prevent any doubt as to which form is intended in this paper. There is, however, a marked difference in size between the Arnside specimens and the reef-like masses which occur in the *Camarophoria-isorhyncha* Sub-zone below; neither does the latter form show the well-developed epitheca characteristic of the Arnside specimens. *M. tenuisepta* is also fairly abundant in the Arnside section, and grows to a considerable size. A list of the fauna from this locality has already been given (see p. 468). M'Coy's type-specimen of *Cyathophyllum multilamellatum* preserved in the Sedgwick Museum was probably obtained from this bed. Specimens of *Chonetes carinata* occur abundantly, with the keeled valve lying uppermost. On the shore close to the Crown Hotel, large specimens of *Caninia* cf. *cylindrica* occur, crushed perfectly flat; and Dr. Sibly informs me that he has met with the same form, similarly flattened, at the same horizon in the Mendip area. West of the bathing-house, the beds crop out at intervals along the foreshore, while a small fault which runs down the bay to the east of New Barns Farm brings in the beds with *Chonetes carinata* again, north of the farm. At Blackstone Point the junction of the *Michelinia* Zone with the beds of the overlying zone is well seen in the old quarry, and in the cliff to the west of the limekiln. *Caninia cylindrica* occurs here in great plenty.

The *Clisiophyllum-multiseptatum* Band is well exposed above the limekiln at Blackstone Point, as a bed of dark shale containing abundant specimens of the index-fossil, together with *Zaphrentis enniskilleni* and *Cyathophyllum multilamellatum*. This layer is immediately overlain by the earliest *Lithostrotion* seen in the section, and may conveniently be taken as the dividing-line between the *Michelinia* Zone and the *Productus-corrugato-hemisphericus* Zone.

The occurrence of *Zaphrentis enniskilleni* in beds representing C_2 of the Bristol succession deserves some comment. The exact horizon of the beds in which it was first collected in Ireland does not appear to be known, but the species was originally considered to be characteristic of D_2. A closely similar, if not identical, form has lately been recorded from S_2(?) by Mr. James Douglas [1] from County Clare, and is found also, as mentioned above, with variants in the upper portion of the Ashfell Sandstone, below the *Cyrtina-carbonaria* Sub-zone, and therefore in beds of an age equivalent to S_1 of the South-Western Province. In the Isle of Man I have found this species occurring abundantly in the lower beds exposed on the shore at Ronaldsway (Derbyhaven), where it is associated with *Michelinia grandis*, *Chonetes carinata*, *Syringothyris cuspidata*, and the large forms of *Schellwienella crenistria* recorded from Arnside. This association is found nowhere in the North-Western Province outside the *Michelinia* Zone, and it seems more than probable that the horizon of the Ronaldsway Beds in the Isle of Man lies near the top of C_2 and the base of S of the South-Western Province.

[1] Q. J. G. S. vol. lxv (1909) p. 554.

It is true that no specimens of *Zaphrentis konincki* have been found in the Ronaldsway Beds, although I have specially sought for them; it is difficult, however, to ignore the weight of evidence derived from the above association. Dr. Wheelton Hind has expressed the opinion that the Ronaldsway Beds of the Isle of Man belong to the *Dibunophyllum* Zone,[1] and the same author has expressed to me his strong conviction that the Arnside Beds are also of *Dibunophyllum* age. It is possible that this view was founded, in part, at all events, on the presence of *Zaphrentis enniskilleni* in both sections. In the Isle of Man, however, that form is not confined to these lower beds, but passes up into beds which are (at all events) high in S if not actually of *Dibunophyllum* age. All the beds of the succession are dark argillaceous and bituminous limestones, and it seems highly probable that we have here an example of the dependence of faunal development on lithological character, and that *Z. enniskelleni* continued to flourish in the Isle of Man area through a considerable period of time—as long as the conditions remained suitable. At Arnside, on the other hand, the typical corals of the argillaceous *Chonetes-carinata* Beds disappeared with the subsidence which introduced clearer water conditions and white limestone deposits. Where *Zaphrentis enniskilleni* occurs in the Upper *Dibunophyllum* Zone in other areas, it is again associated with argillaceous limestones.

The *Productus-corrugato-hemisphericus* Zone is characterized by the absence of the sandstone episode of the type-districts, the beds being fairly fossiliferous throughout. The lower portion is a dark crinoidal limestone, fossiliferous at the base, but becoming compact and rather barren towards the summit. The upper portion is a pure pale-grey limestone, compact near the base but platy above.

The Gastropod Beds form a semicircular outcrop round the northern base of Arnside Knott, and overlie the *Michelinia* Bed of the coast. The upper boundary lies round about the 200-foot contour on the north-eastern flank of the Knott, but there is no hard-and-fast line of division between the two portions of the zone. The beds are seen in the upper part of the cliff near Arnside, behind New Barns Farm, in Gubbins Wood and Frith Wood; and between Blackstone Point and the edge of the salt marsh to the south of Arnside Point, where they are much altered, and roughly cleaved by close-set vertical joints. They are also occasionally exposed in the upper portion of Arnside village, when foundations are being dug for new buildings; they are fairly fossiliferous, and towards the base contain a band of small *Seminula ficoidea*. The fauna is in some respects similar to that of the underlying *Michelinia* Beds, but it is devoid of *Michelinia* and *Chonetes carinata*, and abounds locally in specimens of *Lithostrotion*. The higher and more massive

[1] 'The Palæontological Succession of the Carboniferous Rocks in the South of the Isle of Man' Proc. Yorks Geol. Soc. n. s. vol. xvi, pt 2 (1907) p. 39.

portion of the sub-zone is well exposed in a series of quarries under the Red Hills, where it contains a sparse fauna consisting chiefly of Bellerophons preserved as casts.

The *Nematophyllum-minus* Sub-zone reaches a thickness of 350 to 400 feet on Arnside Knott, and forms the whole of the Knott above the Red Hills. The lower portion, a compact cream-coloured limestone, is well exposed at Hare Parrock on the western flank of the Knott, and is frequently quarried in the district, as at Wharton Crag and Sandside. *Productus-corrugato-hemisphericus*, *Chonetes papilionacea*, and *Seminula ambigua* occur in some abundance. The upper portion abounds with specimens of *Chonetes papilionacea*, which in places give a fissile character to the bedding-planes. Occasional masses of *Nematophyllum minus* in the position of growth occur, and these persist to the summit of the Knott. On the coast the beds are disturbed by small faults and crushes, and in places are much jointed, and stained with hæmatite. The general outcrop is shown in the map (Pl. LIV). The Bryozoa Band has not been recognized in this district.

The Lower *Dibunophyllum* Sub-zone covers a considerable area to the south and east of Silverdale village, the prevalent dip being southwards and south-eastwards; but east of Silverdale Green the beds turn over to the east, as they approach the disturbance which runs near Silverdale Station. The beds are also well exposed along the coast, between that station and Jenny Brown's Point.

The *Chonetes*-aff. *comoides* Band crops out at intervals along the shore, and is here specially rich in specimens of *Cyrtina septosa*; it is overlain by markedly-brecciated beds containing elongated concretionary structures—the 'Stick Bed,' which is constantly found associated with this band in all the western districts.

No beds that can be definitely assigned to the Upper *Dibunophyllum* Sub-zone occur in the Silverdale section. West of Jenny Brown's Point the band is brought in again by a small strike-fault; the pseudo-breccia beds here show a more definite brecciated structure than usual, the fragments being cemented by hæmatite and calcite. In places, however, the brecciated beds appear to pass laterally into ordinary compact limestones.

In Middlebarrow Quarry, close to the Furness Railway, an interesting thrust-plane, making a small angle with the bedding and hading nearly due east, has been laid bare by the quarrying operations (Pl. XLV, fig. 2, facing p. 512). The exposure is unfortunately being rapidly quarried away: this is much to be regretted, as it is seldom that so clear a demonstration of the effects of a strike-fault is to be seen in the field.

(2) The Arnside District East of the Furness Railway.

That portion of the Arnside District which lies east of the Furness Railway presents the same general development as the area

just described, but contains in addition the higher portion of the *Dibunophyllum* Sub-zone, which towards the south passes upwards into the Millstone Grit. The palæontological succession is perfectly normal; the beds of the Upper *Dibunophyllum* Sub-zone belong here to the Western or Kirkby Lonsdale Type. This area is separated from the western tract by Arnside Moss and Silverdale Moss, which appear to mark a dislocation running roughly parallel with the railway, as the result of which the beds are frequently tilted vertically and in places are even reversed. The oldest rocks seen occur near Black-Dyke Cottage, on Arnside Moss; they appear to represent a fragment of fault-breccia belonging to the *Camarophoria-isorhyncha* Sub-zone, and contain *Lophophyllum meathopense*. The *Chonetes-carinata* Beds are well exposed on the south side of the road between Arnside and Sandside, and, near the summit, include the *Cyathophyllum-multiseptatum* Band. Near Dick-Fell Cottage the beds dip steeply eastwards; but, before reaching the railway-bridge, they become vertical, and a little farther on along the shore become inverted with an apparent dip of 70° north-westwards. The inverted position of the beds is confirmed by the fact that the shells of *Chonetes carinata* have their concave valves exposed by weathering; whereas, in normal sections on Arnside shore and elsewhere, the keeled convex valve is almost invariably found projecting from the weathered upper surfaces of the bedding-planes, showing that it is the under surface of the beds which is here exposed. The best section of these inverted beds is seen in the railway-cutting south-west of Sandside Station. At the western end of the cutting the highest beds of the *Michelinia* Zone are found dipping with a reversed inclination towards the south-west, followed by beds which, though apparently underlying them, belong in reality to the Gastropod Beds of the succeeding zone. The great pressure to which the beds have been subjected is shown by the marked development of phacoidal structure, and by slickensiding on the surfaces of the bedding-planes, testifying to intense horizontal movement. On this account the zonal succession is rendered exceedingly obscure, and it is not until we reach the eastern end of the cutting that the beds resume their normal characters, and we find beds marked by layers of *Chonetes papilionacea* dipping gently towards Sandside Station. A small section opposite the station contains *Nematophyllum minus*, and the beds are seen to form part of the dome in which Sandside Quarry is excavated. The inverted *Michelinia* Beds are again exposed along the line of strike, in a small quarry at the corner of the cross-roads near Hazelslack Tower. Here the reversed shells of *Chonetes carinata* and the phacoidal and slickensided surfaces are again noticeable. The line of strike of these vertical and reversed beds can be traced in a southerly direction past the east side of Haweswater and thence through Trowbarrow Hill, to the south of which the beds disappear under Storrs Moss, cut off apparently by a north-and-south cross-fault. The strike of the vertical fold, however, is oblique to the strike of the beds, so

Fig. 1.—*Trowbarrow Quarry, Silverdale, showing vertical beds of* D_1.

E. J. G. photo.

Fig. 2.—*Middlebarrow Quarry, Silverdale, showing thrust-plane in* D_1.

E. J. G. photo.

that on Trowbarrow the fold has affected the beds of the Lower *Dibunophyllum* Sub-zone, and the *Michelinia* Beds do not again appear at the surface.

The *Productus-corrugato-hemisphericus* Zone crops out to the east of the *Michelinia* Beds, the beds being also reversed along the north-and-south line of disturbance. The *Nematophyllum-minus* Beds are well exposed in Sandside Quarry, where they occur in the dome-shaped fold already mentioned.

The Lower *Dibunophyllum* Sub-zone comes on at the summit of Sandside Quarry, where the beds show distinct traces of horizontal movement; they form the highest ground between Sandside and Hale, and in many places the pseudo-breccia beds constituting the summit of the sub-zone are well exposed. Farther south-west the beds of this sub-zone come under the influence of the north-and-south line of disturbance, and on Trowbarrow Hill they are tilted into a vertical position. The massive limestones here include a band of calcareous shale 16 feet thick, which, being more readily denuded than the limestones, is marked along the summit of the ridge by a trough-like depression, a feature whence the hill doubtless derived it name. Both the shale and the limestone are now well exposed in the quarry (Pl. XLV, fig. 1, facing p. 512). The horizon of these beds appears to lie near the summit of the Lower *Dibunophyllum* Sub-zone, and the limestone includes beds of the 'spotted' rock characteristic of this horizon. The limestone is much hardened and recrystallized, and fossils are difficult to identify. Specimens of *Lithostrotion* cf. *portlocki*, *Dibunophyllum* and *Productus* cf. *maximus* have, however, been collected from the bedding-planes exposed on the eastern face of the quarry. The shale-bed, which is a concretionary calcareous mudstone, contains a fair number of fossils, but many of these (and especially the corals) are much compressed. The following species have been collected from this shale-bed:—

Aulophyllum cf. *pachyendothecum* Thomson.
Caninoid *Campophyllum*.
Carcinophyllum ϕ Vaughan.
Clisiophyllum aff. *keyserlingi* M'Coy.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum ϕ Vaughan.
Lophophyllum sp.
Lithostrotion cf. *irregulare* (Phill.).
Lithostrotion junceum (Fleming).
Lithostrotion m'coyanum Ed. & H. East side.
Lithostrotion cf. *portlocki* (Bronn). East side.

Athyris planosulcata (Phill.).
Chonetes compressa Sibly.
Chonetes hardrensis Phill.
Chonetes cf. *interstriata* Dav.
Dielasma sp.
Productus elegans M'Coy.
Productus fimbriatus Sby.
Productus cf. *latissimus* Sby.
Productus cf. *maximus* M'Coy.
Productus semireticulatus Mart.
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Spirifer bisulcatus Sby.

Edmondia sulcata (Phill.).
Posidoniella sulcata Hind.
Posidoniella sp.
Pterinopecten cf. *rigidus* (M'Coy).
Sanguinolites sp.

Loxonema rugiferum Phill.

Orthoceras sp.
Vestinautilus sp.

This shale probably represents the argillaceous band near the summit of the Lower *Dibunophyllum* Sub-zone, exposed in the railway-cutting west of Kent's Bank Station in the Grange District. The altered limestones on the western face may possibly contain a few feet of the overlying Upper *Dibunophyllum* Sub-zone.

On the south of Storrs Moss another excellent exposure is provided by Wharton Crag. The beds, though still showing signs of crushing, dip at a much lower angle, and appear to form portions of a dome cut off on the west and north by faults. The southern margin also shows evidence of an important disturbance running close to the road, as the beds are here much tilted and crushed, and stained by hæmatite. This disturbance must represent a dislocation of considerable magnitude, as at Ing's Point it brings the Gastropod Beds against a sandstone which may represent a part of the Millstone Grit Series, as suggested in the Geological Survey map. The mass of limestone forming Wharton Crag belongs to the *Productus-corrugato-hemisphericus* Zone, but beds of the Lower *Dibunophyllum* Sub-zone come in immediately to the north.

The Upper *Dibunophyllum* Sub-zone is only represented north of Carnforth by a small patch of dark bituminous limestone to the east of Leighton Beck, containing the *Girvanella* Nodular Band. Farther south, however, near Borwick and to the south of Nether Kellet, the sub-zone is exposed at several points on the west side of the Kendal Fault. In all the exposures the beds are tilted into a more or less vertical position, and represent an horizon near the summit of the sub-zone. They are usually much altered, and fossils are poorly preserved. The best continuous section of these beds is exposed in a series of old quarries near Park House, south of Over Kellet. The beds here terminate abruptly towards the south, and appear to be cut off by an east-and-west disturbance of considerable importance; whether this is of the nature of a thrust or not, it is difficult to say.

(3) The Southern Inliers.

The two inliers of Carboniferous Limestone which occur in the Millstone Grit country near Swantly and Halton Green are of considerable interest. My attention was first called to these by Dr. Marr, who had noticed their lithological resemblance to the knoll-reef limestones of the Cracoe District. They appear to represent a western extension of the series of knoll-reef limestones which crop out west of Sladburn, and are mapped by the Geological Survey as faulted on all sides against the Millstone Grit.

The Swantly Inlier consists of crystalline cream-coloured limestone, but contains also darker portions. The beds appear to have been subjected to considerable pressure, and much of the rock is unfossiliferous; patches of fossiliferous rock, however, occur,

and the fossils are here entirely recrystallized. The bedding is throughout obscure, and the lithological changes abrupt. The rock is not well exposed, and so the mutual relations of the different outcrops are difficult to determine. It is possible that portions of the rock represent a breccia similar to that exposed at Halton Green described below, derived from several horizons.

Fauna.

Lithostrotion portlocki (Bronn).

Athyris planosulcata (Phill.).
Productus costatus Sby.
Productus martini Sby.

Pugnax pugnus (Mart.).
Reticularia lineata (Mart.). Common.
Spirifer bisulcatus Sby.
Spirifer cf. *duplicicostus* Phill.
Spirifer cf. *striatus* Fischer.

This fauna, although scanty, shows a close resemblance to that collected from the Botany Beds in the Middleton-in-Teesdale District, and certainly represents beds high up in the *Dibunophyllum* Zone.

The Halton-Green Inlier.—The exposure near Halton Green appears to belong to the same general horizon as that at Swantly, and to have been brought into its present position by the same set of earth-movements. It affords, however, a much better section, and throws a great deal more light on the origin of these interesting inliers. The beds are exposed in an old quarry in Halton Park high up on the right bank of the Lune Valley. The exposure consists of two portions. In the western corner, the quarry has been excavated in a compact, nearly barren, stratified limestone; while in the weathered portion close to the limekiln we find an intensely brecciated mass, composed of angular and subangular fragments, many of which are rich in fossils: these, however, are usually rather fragmentary and badly preserved (Pl. XLIV, fig. 2, facing p. 486). The fossils are not distributed regularly through the breccia, but are confined to certain blocks, many of the fragments being quite unfossiliferous. The breccia indeed appears to be derived from several different beds of limestone, and to represent a crush-breccia on a large scale. It resembles in many respects that described by Mr. Tiddeman from Winterburn and elsewhere in the knoll-reef country near Gargrave[1]; and it is highly probable that the blocks belong to the series of crystalline limestones which, as shown by Dr. Marr, are characteristic of the knoll-reef country south of the Craven Fault,[2] and that they owe their present position to the series of thrust-movements which that author has suggested as having taken place in connexion with the Middle Craven Fault in the neighbourhood of Settle.

[1] Trans. Leeds Geol. Assoc. pt. vi (1891) p. 111.
[2] Q. J. G. S. vol. lv (1899) p. 339.

Fauna.

Carcinophyllum sp.
Cyathophyllum murchisoni Ed. & H.
Dibunophyllum cf. *muirheadi* Nich. & Thomson.
Lithostrotion m'coyanum Ed. & H.
Lithostrotion cf. *martini* Ed. & H.
Syringopora.
Zaphrentis cf. *enniskilleni* Ed. & H.

Fenestella plebeia M'Coy.

Athyris planosulcata (Phill.).
Chonetes cf. *papilionacea* Phill.
Dielasma hastatum (Sby.).
Dielasma cf. *sacculus* (Mart.).
Leptæna analoga Phill.
Productus costatus Sby.
Productus latissimus Sby.
Productus cf. *maximus* M'Coy.
Productus striatus Fischer.
Pugnax acuminatus (Mart.).
Pugnax pleurodon (Phill.).
Pugnax pugnus (Mart.).
Reticularia lineata (Mart.).
Spirifer bisulcatus Sby.
Spirifer duplicicostus Phill.
Spirifer triangularis Mart.

Gervillia squamosa Phill.
Posidoniella pyriformis Hind.

This fauna is of considerable interest, especially with respect to the brachiopoda. Such forms, for instance, as *Pugnax acuminatus* and *Spirifer triangularis* are only known to me from rocks lying south of the Craven Faults: therefore, so far as the scanty fauna collected can be taken as affording an indication of the position of these rocks, it would appear to emphasize the view suggested by the physical characters—namely, that we are here dealing with fragments of the higher limestones of the knoll-reef country in the south-east, brought into their present position by extensive thrusting.

V. The Kendal and Kirkby Lonsdale Districts.

The Kendal District.

This district forms a connecting-link between the Shap and the Arnside Districts, not only on account of its geographical position, but also on account of the lithological and palæontological characters of the strata. The district forms an elongated strip about 9 miles long by 3 miles wide, stretching from Hall-Head Farm southwards to the northern boundary of the Arnside District. The development in this district, as displayed in the exposures between Kendal and Scout Scar, resembles that found in the eastern portion of the Arnside District. The succession differs from that already described in the Shap District in the following characteristics:—

1. In the absence of the greater portion of the *Solenopora* Sub-zone.
2. In the absence of the Brownber Pebble-Bed, which has apparently thinned out here and is represented only by a bed of very compact and gritty oolite containing *Syringothyris cuspidata*.
3. In the absence of the sandstone episode, which is so characteristic of the *Michelinia* Zone and of the overlying Gastropod Beds in the Shap District.
4. In the absence of the greater part of the *Dibunophyllum* Zone, which is only represented by the lower portion of this zone in two places: namely, in the neighbourhood of the Serpentine Walks, and north-east of Haversham in the southern portion of the district.

On the other hand, the succession agrees with that in the Shap and Ravenstonedale Districts in the presence of the *Cyrtina-carbonaria* Sub-zone and the *Thysanophyllum-pseudovermiculare* Band. It differs, therefore, from the development noted in the Arnside District by the presence of these horizons, which are absent from that district and from the districts farther west.

The district is directly continuous with the Arnside District on the south, but is otherwise bounded by Silurian rocks. On the west the beds that form magnificent escarpments of Cunswick Scar and Scout Scar rest unconformably upon a platform of Bannisdale Slates; while on the east the Carboniferous rocks are again brought against the Silurian by the great fault which passes through Kendal and runs southwards, past Farlton to the neighbourhood of Lancaster. A small offshoot of this main fault near Kettlewell, immediately north-west of Kendal, brings up a fragment of the lower beds on the east, and thus the *Michelinia* Zone is exposed on both sides of the district.

At four places outliers of Lower Carboniferous rocks are preserved on the Silurian platform to the east, namely: at Skelsmergh, Grayrigg, Strickley, and Low Bendrigg; they may, for convenience, be included in this district. A fifth outlier, lying on the eastern edge of the district, occurs immediately west of Summerlands; and, although it appears on the 1-inch map of the Geological Survey as forming part of the main mass of Carboniferous Limestone lying to the west of the Kendal Fault, it belongs really, as shown by its fauna, to the eastern or upthrow side of the fault. All these five outliers are composed of beds belonging to the *Seminula-gregaria* Sub-zone, and with the exception of that near Summerlands, to be described later, call for no special description. The Grayrigg outlier contains the whole of the sub-zone, from the Algal Layer up to the *Thysanophyllum* Band, and includes also a few feet of the overlying Lower *Michelinia* Beds with *Cyathophyllum* cf. *multilamellatum*. The development is identical with that observed at Brigsteer; but the beds are much altered, and for the greater part unfossiliferous. The finest exposure of the upper beds occurs in an old quarry west of Cockin.

It will be best first to describe the development of the zones in the northern portion of the district, where excellent exposures occur, and afterwards to mention a few points of interest exhibited by the beds in the southern portion. The general dip is eastward, and averages from about 5° to 8°; but in the southern portion the beds roll slightly, and the dip changes locally.

(1) The Northern Portion.

The slope of the country as shown in the section (Pl. LVI, fig. 3) very nearly coincides with the dip of the rocks, and the greater portion of the surface is occupied by the beds of the *Nematophyllum-minus* Sub-zone.

The *Athyris-glabristria* Zone crops out at intervals along the base of the western and northern portions of the escarpment. The basement-beds are usually obscured, and though a somewhat extensive area at the northern end of the district is represented as occupied by these beds on the Geological Survey map, very few exposures occur at the surface.

The lowest beds met with consist of sandy dun-coloured dolomites, containing little in the way of fossils except obscure plant-remains. Between Hall-Head Farm and Cunswick Hall a series of dolomitic limestones are exposed on both sides of the road; the lowest few feet of these appear to belong to the summit of the *Solenopora* Sub-zone, and contain a few specimens of *Camarotœchia proava* and *Seminula* aff. *ficoides*. The beds, therefore, correspond generally with the lowest horizon found at Low Meathop in the Arnside District, already described; no specimen of *Solenopora* has, however, been met with in this district. The lowest beds usually exposed belong to the Algal Layer, but the typical algal structure can only occasionally be identified in microscopic sections. Certain porcellanous layers, which occur near the base of the sections in Hall-Head Quarries, are of interest, as they closely resemble layers of a similar character that are found in the Bryozoa Band of the Shap District and, like them, contain *Calcispheræ* associated with plant-remains (see Pl. XLVII, fig. 4).

The *Thysanophyllum* Band is well exposed immediately above these beds in Hall-Head Quarries, and from here to Cunswick Hall it forms a nearly continuous outcrop. Farther south it is well exposed in the cutting for the Kendal-Underbarrow road, and again in Crag-Mollet Scar immediately above Brigsteer village. The fauna is normal, and examples of *Cyathophyllum* aff. *multilamellatum* are found near the summit.

Interesting evidence of horizontal movement may be observed in the limestone forming the floor of Hall-Head Quarries, where certain layers have been pinched up into sharp anticlinal folds, while those immediately above and below still remain horizontal and undisturbed; one of these pinched anticlines is shown in Pl. XLVI, fig. 1 (facing this page). The lateral displacement which gave rise to this interesting phenomenon was doubtless connected with the movements that brought down the Carboniferous rocks against the Silurian at Kendal hard by. Such lateral movement is common throughout the North-Western Province—as shown by the variation in the thickness of certain shale-partings, and also by the slickensiding constantly observed on the surfaces of the bedding-planes.

Above the *Thysanophyllum* Band under Cunswick Scar occurs a bed of hard siliceous limestone, which forms a small scar a few feet thick. Many of the layers are oolitic, while others are almost entirely composed of sand-grains cemented by calcite. The deposit is not very fossiliferous, but contains a few well-preserved specimens of *Syringothyris cuspidata*, and it was doubtless from

Fig. 1.—*Fold in* Thysanophyllum *Band, Hall Head Hall, Kendal.*

E. J. G. photo.

[This view shows horizontal movement along the bedding-plane AB.]

Fig. 2.—*Pseudobreccia and 'Stick Bed,' Lower* Dibunophyllum *Sub-zone, Chapel Island, Furness.* *(See p. 533.)*

E. G. photo.

[The pseudo-breccia structure is shown at C.]

this bed that the specimen was obtained which is figured by Davidson from the Kendal District.[1] This bed appears to be the attenuated representative of the Brownber Pebble-Bed of the Shap District, as it occurs at about the same horizon; while the presence of *Syringothyris cuspidata* is in keeping with this view. The band also closely resembles the gritty compact limestone with *S. cuspidata*, which crops out in Swindale Beck behind Roman Fell, in the Pennine District. The following species occur in this bed[2]:—

Cyathophyllum cf. *multilamellatum* M'Coy.
Zaphrentis koninckı Ed. & H. (mutation).
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Spirifer furcatus M'Coy.
Syringothyris cuspidata (Mart.).
Aviculopecten sp.

The *Michelinia* Zone.—The most important outcrop of this zone occurs along the face of the western escarpment; but the zone is again exposed on the east side of the district at Kettlewell, where it is brought up by an offshoot of the main Kendal fault. The lower sub-zone, corresponding to the beds which occupy the summit of Meathop Fell, is only found on the western escarpment, where it is represented by 20 to 30 feet of pale, somewhat platy, siliceous limestone, which crops out on each side of the cart-track immediately above Crag Mollet. This bed contains large examples of *Michelinia grandis*, together with *Camarophoria isorhyncha*. On the west side of the track, at a slightly lower horizon, the limestone contains abundant remains of *Cyathophyllum* cf. *multilamellatum* partly silicified. These are the earliest examples of *Cyathophyllum* met with in the North-Western Province, and are found also at this horizon at Hall Head, in the outlier at Grayrigg, and at Cat Crag and Broad Oak in the Grange District.

The *Chonetes-carinata* Sub-zone crops out at intervals along the foot of the main escarpment below Helsington Barrows; but the beds are best exposed in the cutting for the Brigsteer-Kendal road. The total thickness of the *Michelinia* Zone here is between 150 and 170 feet. The beds of the upper portion of the zone consist of impure limestone and shaly calcareous mudstone, similar to those seen in the Storth-Road section and on the foreshore at Arnside; and, though not abundantly fossiliferous, they contain most of the characteristic species of the sub-zone. This section is an important one, since it shows clearly the position of the *Thysanophyllum* Band relatively to the overlying *Michelinia* Zone. Farther north, the beds are well exposed on each side of the Kendal-Underbarrow road. As in the case of the underlying

[1] 'Brit. Foss. Brachiopoda' Monogr. Palæont. Soc. vol. ii (1858–63) pl. viii, fig. 20.

[2] This bed is mentioned by Mr. R. H. Tiddeman in the revised Survey Memoir on the district, and correlated by him with a portion of the Orton Sandstone Series, one of the many examples of the careful deductions made by that acute observer on stratigraphical grounds alone. See 'The Geology of the Country around Kendal, &c.' Mem. Geol. Surv. 2nd ed. (1888) p. 29.

Athyris-glabristria Zone, the beds rise gradually in this direction, and so, while the base of the zone on the Brigsteer-Kendal road lies at a height of about 220 feet above O.D., on the Underbarrow-Kendal road (2½ miles farther north) it has risen above the 500-foot contour-line.

The *Michelinia* Zone which crops out at Kettlewell, on the east side of the district, is similar in character to that exposed above Brigsteer, and the beds contain the usual fauna. The *Clisiophyllum-multiseptatum* Band, with *Zaphrentis enniskilleni*, is also present at this locality.

The *Productus corrugato-hemisphericus* Zone: the Gastropod Beds occupy the surface over a considerable area in this district. On the west, under Scout Scar, the beds are usually covered by screes, while the Plumgarth Quarries opened in these beds north-west of Kendal are almost devoid of organic remains, except specimens of *Bellerophon* and *Productus*. The large quarries at Kendal Fell have, however, furnished numerous fossils to local collectors, and a rich assemblage is preserved in the Kendal Museum. The most interesting feature of this collection is the great number of species of mollusca and the large size which many of the gastropods and cephalopods attained, recalling Mr. Douglas's description of a similar rich molluscan fauna from the limestone of County Clare, which, however, belongs to a lower horizon.[1] A list of this collection is given in the Geological Survey Memoir on the Kendal District, 2nd ed. (1888) table iv, pp. 85–88. Some of the species in this list are, however, incorrectly named.

The *Cyrtina-carbonaria* Sub-zone is well developed, especially on the east side, where the beds are exposed in the upper portion of the old Kettlewell Quarry.[2]

The *Nematophyllum-minus* Sub-zone forms the greater part of the high ground, from the edge of Scout Scar and Cunswick Scar to the summit of the Kettlewell Quarries. It was doubtless from this locality that M'Coy obtained his type-specimen of the index-fossil now preserved in the Sedgwick Museum at Cambridge. Masses of this coral occur in the upper layers of the white limestone on Scout Scar; on Cunswick Scar above Kettlewell; and in the neighbourhood of 'The Heights.'

The Bryozoa Band, which lies at the summit of this zone in the Shap and Ravenstonedale Districts, has not been noticed here; this may be due to the denudation of the highest beds of the zone, but it is possible that the band has died out in this district, as it is nowhere met with farther west.

[1] Q. J. G. S. vol. lxv (1909) p. 551.

[2] The specimens figured by M'Coy in the 'Brit. Pal. Fossils' 1855, pl. iii *d*, figs. 12–18, under the name '*Pentamerus carbonarius*,' and by Davidson 'Brit. Foss. Brachiopoda' Monogr. Palæont. Soc. vol. ii (1858–63) pl. xv, figs. 7–12, were obtained from this locality.

The Lower *Dibunophyllum* Sub-zone is only represented by a small thickness of limestone in the 'Serpentine Walks.'

(2) The Southern Portion.

From Brigsteer as far south as Gilpin Bridge and the mouth of the Kent, the lower beds are a continuation of the sequence described above. The dip is uniformly eastward, and the beds of the *Seminula-gregaria* Sub-zone form a low cliff, bordering the Gilpin estuary. They crop out at the surface in Brigsteer Park, and are also well exposed in a series of old quarries in the neighbourhood of Cinderbarrow; but the beds are here almost devoid of fossils. The overlying *Michelinia* Beds extend somewhat farther east in the neighbourhood of Sizergh Castle. To the east of Sizergh an interesting inlier of the upper portions of the *Michelinia* Zone occurs in the valley of the Kent (the Kent Inlier), between Hawes Bridge and Levens Park. The beds are disposed in a broad anticlinal fold, the axis of which strikes east and west; locally, however, the dip is modified by several minor folds, some of which are well shown in the river-bank between Sedgwick and Levens.

The *Clisiophyllum-multiseptatum* Band is exposed above Hawes Bridge, and the beds here contain the general assemblage found at Blackstone Point; while, near the southern end of the inlier, somewhat lower beds are found, which have yielded *Michelinia grandis*, *Cyathophyllum multilamellatum*, and other common Arnside species.

The *Nematophyllum-minus* Sub-zone, which forms the southern end of Scout Scar, does not extend far southwards, the southernmost exposure where *N. minus* has been found occurring behind Grate Farm. East of the Kent Inlier the Gastropod Beds come on, but the *N.-minus* Beds are again met with in the railway-cutting south-west of Oxenholme Junction, about half a mile east of Natland: here the beds are much crushed and altered by their proximity to the Kendal Fault. No beds belonging to the *Dibunophyllum* Zone have been traced in this portion of the district. South of the Kent drainage-area the geological structure of the district becomes more complicated. The country is heavily covered with drift, and very few exposures occur: this is especially the case in the eastern portion of the area. The chief feature is an important disturbance running in a general east-and-west direction in the neighbourhood of Hincaster, between Levens Hall and Heversham. Owing to the absence of any outcrop south of Stainton, it is impossible to gauge the extent or direction of this disturbance; to the south of it, however, we find massive limestones that belong to the Lower *Dibunophyllum* Sub-zone dipping due northwards at 25° to 30°, and forming the high ground between Leasgill and High Greenside, immediately north-east of Heversham. This dip would carry them under the *Michelinia* Beds in the Kent

Inlier, described above; and, as there are no beds of Lower *Dibunophyllum* age on the north, there is evidently a considerable dislocation in this neighbourhood.

Another interesting example of the value of the zonal method in detecting disturbances in these rocks may be quoted from this district. On the eastern edge of the Carboniferous Limestone area, the Kendal Fault is shown in the Geological Survey map as curving outwards rather sharply to the east near Summerlands. This protruding portion of Carboniferous rocks should, therefore, consist of the highest beds in the district, as the dip, when last seen, is eastwards. Fortunately, an exposure is met with in some small quarries in Eskrigg Wood, just where the greatest eastward extension of these Carboniferous rocks is shown in the Geological Survey map. The following forms have been obtained from these beds :—

Calcareous alga.

Campophyllum ciliatum, sp. nov.
Lophophyllum meathopense, sp. nov.

Syringopora cf. *geniculata* Phill.

Seminula aff. *ficoidea* Vaughan.

This fauna is met with nowhere in the North-Western Province, except at the base of the *Seminula-gregaria* Sub-zone: therefore this protruding portion of the Carboniferous outcrop must belong, not to the western side of the Kendal Fault, but to the Silurian area on its eastern side, as shown in the accompanying map (Pl. LIV). It must once have formed part of a continuous spread of limestone overlying the Silurian on the upthrow or eastern side of the fault, of which the outliers at Strickley, Low Bendrigg, Grayrigg, and Skelsmergh are the fragmentary remains.

The Kirkby Lonsdale District.

This district comprises the area occupied by Lower Carboniferous rocks between the Kendal Fault, south of Farleton, and the Dent Fault. It constitutes, on the whole, the most complicated portion of the North-Western Province. This complication is due, in the first place, to the existence of a large number of important dislocations; and secondly to the fact that, so far as the upper beds of the series are concerned, they occupy a geographical position intermediate between the Yoredale type on the north and east, and the knoll-reef type which characterizes the area south and west of the Craven Faults.

The chief dislocations run in a general north-and-south direction, but have a tendency to converge on points, usually northwards, so as to enclose triangular areas of Carboniferous rocks, as shown in the accompanying map (Pl. LIV).

The *Athyris-glabristria* Zone.—A small thickness of rocks which appear to belong to this zone occurs at the northern or pointed end of the western triangular inlier north of Lupton Hall. The beds are exposed on both sides of the road to Lupton-Row Farm, and consist of compact dolomite very much crushed.

The only organic remains that have been obtained from them are badly-preserved remnants of calcareous algæ and *Seminula gregaria*. The occurrence of these fossils, taken together with the lithological character of the beds and their position (apparently underlying the horizon to be next described), leaves little doubt that they belong to the upper portion of the *Athyris-glabristria* Zone, although the country immediately south of these outcrops unfortunately affords no exposures.

The *Michelinia* Zone.—In the neighbourhood of Hunger Hills, on the east side of the outlier, a good section of dark earthy limestones belonging to the upper portion of the *Michelinia* Zone is exposed in an old quarry close to the eastern boundary-fault, while smaller outcrops of the same horizon occur farther west. The beds contain the following fossils :—

Caninia cylindrica (Scouler).
Diphyphyllum aff. *lateseptatum* M'Coy.
Michelinia grandis M'Coy.
Syringopora cf. *distans* Fischer.
Athyris expansa (Phill.).
Chonetes carinata, sp. nov. (MS.).
Productus cf. *corrugato-hemisphericus* Vaughan.
Rhipidomella michelini (L'Éveillé).
Schellwienella crenistria (Phill.); the large Arnside form.

In the upper portion of this exposure occur also *Zaphrentis enniskilleni* and *Clisiophyllum multiseptatum*, which mark the passage-band at the summit of the *Michelinia* Zone in the Arnside District.

The *Productus corrugato-hemisphericus* Zone.—The beds of the lower portion of this zone are not well exposed, but occupy the ground east of the road in the neighbourhood of Lupton Hall, where they are seen in a small anticlinal fold. The *Cyrtina-carbonaria* Beds have not been noticed in this exposure; but a pale crystalline limestone with *Nematophyllum minus* and *Chonetes papilionacea* is exposed on the west side of the road above the lime-kiln opposite Lupton Hall, where the beds are crushed and veined with calcite in the neighbourhood of the western fault. The strike of the beds, as shown on the map, leaves little room for doubt that the outlier is bounded by faults or thrusts on both its eastern and western margins.

The triangular mass of Lower Carboniferous rocks lying between Farleton village and Hutton Roof, which culminates in the conspicuous escarpment of Farleton Fell, forms another isolated mass, cut off apparently on all sides by faults. It includes a complete succession of the zones, from the summit of the *Michelinia* Zone up to the base of the Upper *Dibunophyllum* Sub-zone. The beds dip in a south-easterly direction, the lowest beds being exposed near Farleton village. The succession is normal up to the summit of the Lower *Dibunophyllum* Sub-zone, which includes examples of the lower 'spotted' beds: these are well exposed in Clawthorpe Quarries.

The Upper *Dibunophyllum* Sub-zone crops out west of Hutton Roof, where the beds are seen dipping steeply to the Hutton Roof Fault. They consist of the usual dark limestones, and contain *Productus latissimus* and the following characteristic fossils:—

Caninia cf. *cylindrica* (Scouler); cf. Humphrey Head form.
Dibunophyllum muirheadi Nich. & Thomson.
Lithostrotion irregulare (Phill.).
Lithostrotion junceum (Fleming).

East of Hutton Roof we find another good sequence of the upper zones. The Lower *Productus corrugato-hemisphericus* Zone crops out in a small cliff, on the north side of the road from Kirkby Lonsdale to Lupton Beck, which is bounded on the north by a continuation of the eastern Lupton Fault. The *Nematophyllum-minus* Beds are not well exposed; but the beds of the Lower *Dibunophyllum* Sub-zone make, as usual, a considerable feature to the south of the road. They are also well exposed in the River Lune below the bridge.

The dark limestone at the base of the Upper *Dibunophyllum* Sub-zone crops out again in the neighbourhood of Sellet Mill; here the beds are extremely fossiliferous, and contain, among others, the following species:—

Aulophyllum cf. *pachyendothecum* Thomson.
Caninia cf. *cylindrica* (Scouler).
Dibunophyllum muirheadi Nich. & Thomson.
Zaphrentis enniskilleni Ed. & H.
Martinia ovalis (Phill.).
Productus cf. *antiquatus* Sby.
Productus edelburgensis Phill.
Productus latissimus Sby.
Productus semireticulatus Mart.
Productus sulcatus Sby.
Schizophoria resupinata (Mart.).
Spirifer triangularis Mart.

Sections along the Dent Fault.

In the area between the Kirkby Lonsdale and Ravenstonedale districts the Carboniferous rocks have been denuded from the surface, as the result of the uplift on the north-west side of the Dent Fault. With the exception of the outliers east of Kendal already described, the only patches of Carboniferous rocks serving to connect these districts are found in the tributaries of Hebblethwaite Gill and in the River Clough east of Sedbergh. Throughout the greater part of the district traversed by the Dent Fault, its north-western margin is bordered by rocks of pre-Carboniferous age, while the southern side of the fault is occupied, for the most part, by Yoredale Beds. The presence, however, of some of the lower zones, preserved on the upthrow side of the fault in these sections, is of importance, since it affords valuable evidence regarding the date of the Carboniferous submergence of this portion of the North-Western Province.

In Norgill, the northern tributary of Hebblethwaite Gill, the Polygenetic Conglomerate, which is here crowded with blocks of Keisley Limestone, is succeeded by compact cementstones and dark calcareous shales. Some of these shaly layers contain plant-remains

and ostracods, among which *Leperditia okeni* is conspicuous; while in one dark compact band a small rhynchonellid also occurs, together with fish-remains. The *Rhynchonella*, although as a rule badly crushed, appears to be referable to *Rh. fawcettensis*, which, as already mentioned, characterizes in the Shap and Ravenstonedale Districts the *Productus-globosus* Band at the base of the *Seminula-gregaria* Sub-zone. Dr. A. Smith Woodward, who has kindly examined the fish-remains, reports that they include a species of *Deltodus* which is probably new, together with a spine of *Oracanthus*; but the remains are not sufficiently well-preserved for specific description.

In Pennyfarm Gill, the eastern tributary of Hebblethwaite Gill, there is a good section exposed, from the Polygenetic Conglomerate, through basement Carboniferous sandstones with obscure plant-remains, to the lowest beds of Carboniferous Limestone. The beds are dipping at a high angle, and include the upper portion of the *Michelinia* Zone. This zone occurs at a sharp bend in the stream, about 180 yards above the junction of Pennyfarm Gill with Hebblethwaite Gill, and consists of dark impure limestone, which contains, among others, the following fossils :—

Clisiophyllum multiseptatum, sp. nov.
Zaphrentis enniskilleni Ed. & H.
Zaphrentis koninckı Ed. & H.
Athyris cf. *expansa* (Phill.).
Chonetes carinata, sp. nov. (MS.).

This assemblage is characteristic, elsewhere in the North-Western Province, of the upper portion of the *Michelinia* Zone.

The main line of the Dent Fault appears to pass to the east of these beds, and soon brings in the typical Yoredale limestones. The greater part of the *Productus corrugato-hemisphericus* Zone and the Lower *Dibunophyllum* Sub-zone would, therefore, seem to be absent in the section; while the Lower *Michelinia* Zone appears also to be cut out by a subsidiary fault. Farther south-west, in the River Clough, only a small portion of the lower series is exposed on the west side of the fault; while, to the east of it, we find a continuous section of the *Productus* Zone and the Lower *Dibunophyllum* Sub-zone leading up to the Yoredale beds above. The Lower *Dibunophyllum* Sub-zone here also includes the 'spotted' beds already described.

It will thus be seen that the Dent Fault traverses the lower zones of the Carboniferous obliquely, and that, so far as these zones are preserved, they are similar to those found in the Kirkby Lonsdale District on the west, the lowest fossiliferous horizon (as in the Lupton District) being somewhere near the base of the *Seminula-gregaria* Sub-zone.

VI. The Grange and Furness Districts.

The rocks of these districts, forming the northern shore of Morecambe Bay, constitute the southern portion of the ring of Lower Carboniferous rocks bordering the Lake District between the Duddon estuary and Scout Scar. They are divided by a system of north-and-south strike-faults into a series of blocks, separated one

from the other, either by estuaries or by valley-depressions. The general dip of the Carboniferous rocks being uniformly eastward, and the downthrow being on the west of each fault, we find a series of similar blocks of Lower Carboniferous strata, in each of which a complete sequence is exposed from the Silurian to the highest Carboniferous bed (usually somewhere near the summit of the Lower *Dibunophyllum* Sub-zone) remaining, after denudation, in each block (Pl. LVI, Section 3, & fig. 1, p. 451).

The numerous sections of the lower beds thus exposed show that the general surface of the Silurian platform upon which the Carboniferous strata were deposited must have been, on the whole, a remarkably even one, and the Carboniferous submergence must have taken place simultaneously over a large area.

Everywhere resting upon the Silurian rocks occurs some portion of the *Seminula-gregaria* Sub-zone, succeeded by the *Michelinia* Zone. Outside the Furness District there is practically no equivalent of the Shap Conglomerate or the barren basement-sandstone which occurs in the type-districts; still less is there any trace of the underlying Polygenetic Conglomerate of the Sedbergh and Ullswater areas farther east.

The area with which we are now concerned may, for convenience, be divided into an eastern portion—'The Grange District,' and a western portion—'The Furness District,' separated by the Leven estuary.

(1) The Grange District.

This district lies between the Leven estuary and the Kendal District already described. It is separated from the latter by the fault which runs down the Gilpin valley. Four fault-blocks occur in this district. These are, counting from the east to the west: Whitbarrow, Yewbarrow, Hampsfell, and Holker. The succession resembles closely that in the Arnside District, and the beds are, as might be expected, intermediate in their development between those of the Arnside and of the Kendal Districts. Thus the *Thysanophyllum* Band of the type-districts is only found in the easternmost block; while the character of the Upper *Dibunophyllum* Sub-zone, so far as it is preserved at Humphrey Head and Holker, is intermediate between the Yoredale and the Kirkby Lonsdale types. The *Spirifer-furcatus* Band and the *Camarophoria-isorhyncha* Sub-zone are also locally developed.

The Whitbarrow–Yewbarrow block is separated from the Kendal District on the east by the Gilpin-valley Fault, and from the Hampsfell block on the west by the Newby-Bridge & Lindale Fault, which brings up the Silurian tract of Higher Newton and the Winster Valley. Whitbarrow and Yewbarrow are also separated one from the other by a north-and-south fault which passes near Witherslack Hall. The general dip is eastward. The lowest beds are exposed in both Yewbarrow and Whitbarrow, along the base of the western escarpments. The zonal development is intermediate

between that of the Kendal and that of the Arnside District. It differs from the North Kendal succession, chiefly in the more pronounced development of the *Chonetes-papilionacea* Beds near the summit of the *Nematophyllum-minus* Sub-zone.

The *Seminula-gregaria* Sub-zone consists, as usual, of sparingly fossiliferous, purple, magnesian limestones with *Seminula* aff. *ficoidea* and *Cyrtina* cf. *carbonaria*. They are exposed along the foot of the escarpment between Cat Crag and Strickland Hall; and a few feet belonging to the same horizon occur also at the base of the section at Beck Head, in the Whitbarrow portion of the block.

The *Thysanophyllum* Band crops out behind the old lime-kiln between Broad Oak and Row, but appears to die away southwards before reaching Beck Head.

The Brownber Pebble-Bed has not been traced so far west; but a single specimen of *Syringothyris cuspidata* was collected in a compact gritty layer near the base of the escarpment. *Spirifer furcatus*, however, is met with plentifully at Beck Head and at Cat Crag; and the bed in which it occurs may be correlated with the *Sp.-furcatus* Band at the summit of Meathop Fell.

The *Camarophoria-isorhyncha* Sub-zone is found in several exposures at the foot of both of the escarpments, notably at Cat-Crag Cottage and Long-Howe End, and again between Beck Head and Witherslack Hall.

The *Chonetes-carinata* Sub-zone which succeeds in both sections is perfectly normal, though thin, and contains all the common species found at Arnside; while the overlying *Clisiophyllum-multiseptatum* Band is also represented. Both horizons are exposed above Broad Oak and west of Long-Howe End, and again in an old quarry opposite St. Paul's Church. The overlying beds call for no very special description; their general distribution is shown on the accompanying map (Pl. LIV).

The *Cyrtina-carbonaria* Sub-zone has practically died out here; but the *Nematophyllum-minus* Beds are thick as well as fossiliferous, and near the summit contain layers rich in *Chonetes papilionacea*. Both the *N.-minus* Beds and the Gastropod Beds are well exposed at the southern end of Whitbarrow behind Low Fell End. The highest beds met with occur in the small outlier at Gilpin Bank; they belong to the upper 'spotted' beds, and cannot lie far below the base of the Upper *Dibunophyllum* Sub-zone. The *Chonetes*-aff. *comoides* Band has not, however, been noticed in this block.

The Hampsfell block is separated from the Yewbarrow block by a tract of Silurian rocks about 3 miles wide; it lies to the south-west, and forms the largest spread of Lower Carboniferous rocks in the Grange District. It includes the peninsula of Humphrey Head, and the detached outliers of Holme Island and Hazel Rigg. It forms a lenticular mass stretching for about 8 miles in a north-and-south direction from Ayside to Humphrey Head Point, and some 3 or 4 miles in an east-and-west direction from

Lindale to Cartmel. The western outcrop forms a fairly steep escarpment, culminating in Hampsfell Hospice at a height of 727 feet. It rests on the Silurian tract of Cartmel and Broughton, and is cut off on the north-east by the Newby-Bridge & Lindale Fault. On the south-east it forms the coast-line between Castle Head and Humphrey-Head Point, and constitutes the foreshore between Grange and Kent's Bank. The block includes the beds from the *Seminula-gregaria* Sub-zone to the *Lonsdalia-floriformis* Beds at the base of the Upper *Dibunophyllum* Sub-zone. The former, which consist of unfossiliferous purple dolomites, crop out in some old quarries between Cartmel and Cark; they doubtless represent the horizon exposed at the southern end of Meathop Fell. The overlying Lower *Michelinia* Beds are not well exposed; but *Chonetes carinata* and *Caninia cylindrica* have been collected from several exposures, along the base of the escarpment between Birkby Hall and St. Paul's Church near Field Broughton. The outcrops of the higher zones run parallel to this escarpment, or nearly due north and south, as shown on the map (Pl. LV). At the northern end of the block the Lindale Fault cuts across the strike of the Carboniferous rocks, so that successively lower zones are brought against the Silurian as we travel in a north-westerly direction.

The Gastropod Beds occupy the country north and west of the Cemetery, and stretch thence northwards to Hampsfield Hall.

The *Nematophyllum-minus* Beds are well exposed in Haggs Quarry, and the upper portion of the sub-zone shows the shaly development of the *Chonetes-papilionacea* Beds characteristic of the Western Districts.

The Gastropod Beds are not well exposed, and no attempt has been made on the map to separate the upper and the lower portions of the zone, as the *Cyrtina-carbonaria* Beds are again indistinguishable. The beds, however, which crop out in Great Eskett Wood, about half-a-mile south-east of Cartmel, certainly belong to the lower portion of the zone.

The Lower *Dibunophyllum* Sub-zone is exposed in the quarries on the Cartmel Road between the Cemetery and Low-Fell Gate, and here the lower 'spotted' beds are well developed; they can be followed almost continuously along the escarpment to the edge of the wood above Hampsfield Hall. North of this the beds form a broad synclinal fold, and they reappear on the heights of Newton Head to the south of Head-House Farm; while the summit of Hampsfield Fell affords good exposures of the upper beds of the sub-zone, including the bands of pseudo-breccia. These upper beds are brought by the prevailing easterly dip of 10° on to the coast in the neighbourhood of Grange. A good section is exposed in the road-cutting a little to the east of the railway-station, where they are extremely fossiliferous and contain abundant specimens of *Dibunophyllum* ϕ; while the pseudo-breccia beds, including the *Chonetes*-aff. *comoides* Band, are exposed on the foreshore below the promenade. This band is again associated with the peculiar concretionary layer covered with 'stick-like' impressions, which has

already been mentioned as occurring in the Silverdale coast-section at the same horizon. The band itself, which is exposed on the shore on each side of the pier, is conspicuous on account of its more shaly character and its yellower colour, as compared with the beds among which it lies. It contains large examples of *Cyrtina septosa*, together with specimens of *Chonetes* aff. *comoides* and *Productus hemisphericus*. The overlying beds exposed at low tide to the west of the pier cannot be far below the base of the Upper *Dibunophyllum* Sub-zone, and they contain abundant specimens of *Lithostrotion portlocki* and other corals. Brachiopods are, on the whole, rare; but *Productus* cf. *maximus* and *Pr. hemisphericus* are locally abundant. South of Grange promenade no exposures occur on the coast, until we reach Seawood cottages; here and farther south-west, beyond Kent's Bank Station, the beds of the Upper *Dibunophyllum* Sub-zone come on and the Nodular *Girvanella* Band is well exposed. At Kirkhead End these beds are cut off by a small north-and-south fault, which runs down the east side of the Bay opposite Wyke House. This fault brings in again the *Chonetes*-aff. *comoides* Band in the corner of the bay close to the railway-embankment.

A good section of the strata at the base of the Upper *Dibunophyllum* Sub-zone is seen in the railway-cutting immediately to the north. This includes a bed of shale, along which horizontal movement appears to have taken place, as the shale has been nipped out, and occurs in patches between the harder limestone-beds above and below.

On the west side of the Bay, south of Wyke House, the lower beds of the Upper *Dibunophyllum* Sub-zone again appear at the surface, and from here to Humphrey Head a continuous section of these beds is exposed on the foreshore. This section affords one of the best exposures of the *Lonsdalia* Beds to be met with in the North of England. It consists of 20 to 25 feet of grey limestones, including, near the middle, a thin layer of black shale containing specimens of *Chonetes compressa*, while the Nodular *Girvanella* Bed at the base is exposed along the greater part of the section. The nodules are very abundant; they form compact concentric incrustations round small fossils averaging about an inch in diameter, and weather out prominently at the surface. Under the microscope, tubes of *Girvanella* can sometimes be observed, arranged concentrically round the nodules. The greater number of the nodules, though undoubtedly due to organic agency, present a somewhat obscure structure; it seems probable, however, that calcareous algæ, and especially *Girvanella*, directly or indirectly contributed largely to their formation.

The beds are particularly rich in corals, and contain reef-like masses of *Lithostrotion*, *Lonsdalia floriformis*, and *Cyathophyllum regium*. Brachiopods are scarce, but *Productus giganteus* and *Pr. hemisphericus* occur locally in some abundance, while specimens of *Schellwienella* cf. *senilis* occur in patches. The following is a list of species collected from this interesting locality:—

Girvanella sp.

Alveolites capillaris (Phill.).
Aulophyllum sp. (large) cf. *pachyendothecum* Thomson.
Aulopora sp.
Caninia cf. *cylindrica* (Scouler).
Carcinophyllum ϕ Vaughan.
Clisiophyllum aff. *keyserlingi* M'Coy.
Cyathophyllum regium Phill.
Dibunophyllum muirheadi Nich. & Thomson.
Dibunophyllum turbinatum (M'Coy).
Heterophyllia grandis M'Coy.
Lithostrotion junceum (Fleming).
Lithostrotion martini Ed. & H.
Lithostrotion m'coyanum Ed. & H.
Lithostrotion aff. *portlocki* (Bronn).
Lonsdalia floriformis (Fleming).
Lophophyllum sp. Compound form.
Michelinia cf. *tenuisepta* (Phill.). Very small form.
Zaphrentis aff. *constricta* Carruthers MS.
Syringopora geniculata Phill.

Chonetes cf. *compressa* Sibly.
Dielasma hastatum (Sby.).
Orbiculoidea nitida (Phill.).
Productus giganteus Mart.
Productus aff. *grandicostatus* M'Coy.
Productus cf. *margaritaceus* Phill.
Productus quincuncialis Phill.
Productus scabriculus Mart.
Productus semireticulatus Mart.
Rhipidomella michelini (L'Éveillé).
Pugnax cf. *pleurodon* (Phill.).
Schellwienella cf. *senilis* (Phill.).
Spirifer antiquatus Sby.
Spirifer bisulcatus Sby.
Spirifer (*planicostus* M'Coy) = *crassus* de Kon.
Spirifer duplicicostus Phill.
Spirifer aff. *grandicostatus* M'Coy.

Loxonema rugiferum Phill.
Pleurotomaria sp.

The three small outliers of Hazel Rigg, Castle Head, and Holme Island on the east side of the main mass consist of large masses of fault-breccia let down against the Lindale Fault. Holme Island itself consists of a small dome of limestone crushed against the downthrow side of the fault; the beds here lie near the summit of the Lower *Dibunophyllum* Sub-zone. The little outlier of Hazel Rigg probably represents a much lower horizon, near the base of the succession, but the beds are crushed, recrystallized, and quite unfossiliferous. A fault passes between Holme Island and the Meathop outlier, with the result that, whereas the island is composed of beds near the summit of the Lower *Dibunophyllum* Sub-zone, the Meathop outlier, as already shown, contains beds as low as the *Camarotœchia-proava* Band.

In the Holker block we meet with beds from the base of the *Michelinia* Zone to the Upper *Dibunophyllum* Sub-zone; and a nearly continuous section occurs, from the lowest beds at Park Head to near the summit of the Lower *Dibunophyllum* Sub-zone. This block is bounded on the west by the Leven estuary, and is cut off on the east by the Cark-Haverthwaite fault. East of this fault the Silurian rocks form a conspicuous fault-scarp; while, on the west side, the country is occupied by alluvial deposits forming Deer Dyke Moss and Barker Moss, out of which rise several islands of Lower Carboniferous rock.

The *Camarophoria-isorhyncha* Sub-zone is exposed in two sections—one situated between Park Head and Barker Scar, and the other farther north, between Skelwith Hall and Reake Hill in the neighbourhood of Low-Frith Farm, where the two subdivisions of the *Michelinia* Zone are seen in direct upward continuation one

with the other. These sections are of especial interest, since they confirm the conclusion, already arrived at from a study of the Arnside and Kendal Districts: namely, that the bed containing the massive form of *Michelinia grandis*, seen on Meathop Fell, underlies the higher beds of the zone with *Chonetes carinata* exposed on the opposite shore at Arnside. In the Park-Head section the lower portion of the zone is seen at low water in the neighbourhood of Barker Scar, where it consists of about 20 feet of massive limestone containing large specimens of *Michelinia grandis*. This is overlain by dark limestones and calcareous mudstones, forming the upper portion of the *Michelinia* Zone, which crops out on the beach and also in a small cliff farther up the shore below the flagstaff.

The mudstones contain identically the same fauna as that already described from the Arnside Beds, and the section includes the *Clisiophyllum-multiseptatum* Band at the summit.

The *Productus-corrugato-hemisphericus* Zone.—Immediately overlying this band comes a purple limestone with *Lithostrotion* and *Seminula* aff. *ficoides*, representing the lower portion of the *Pr.-corrugato-hemisphericus* Zone; and these beds are succeeded by the paler limestones containing *Nematophyllum minus* and *Chonetes papilionacea*, belonging to the upper portion of the zone. The beds dip here at about 20° south-eastwards.

On the east side of Ravenbarrow Point a small fault occurs, but a good exposure of the overlying beds of the Lower *Dibunophyllum* Sub-zone is seen a little farther east; and these beds can be followed in a northerly direction to Old-Park Farm, where the 'spotted' beds, already mentioned as very characteristic of this zone elsewhere, are found in the quarry in Waitham Wood.

Beds belonging to the Upper *Dibunophyllum* Sub-zone crop out in Holker Park, and consist of a series of sandstones and thin bituminous limestones near Quarry Flat. These deposits appear to approach the Kirkby Lonsdale type in character.

The section near Frith Hall farther north is a continuation of that just described. It is of interest, chiefly on account of the exposure of the beds of the *Camarophoria-isorhyncha* Sub-zone and the evidence which it affords regarding their relation to the overlying beds of the upper portion of the zone, which are also well exposed here.

The lower beds are much indurated, recrystallized, and traversed by calcite-veins, indicating their proximity to a considerable disturbance. The importance of this disturbance is further emphasized by the presence of a thrust-plane accompanied by a red crush-breccia. This breccia is well seen in the cliffs a few feet above the shore, in several places in the neighbourhood of Hazelhurst Point.

These evidences of movement are doubtless connected with the disturbance which runs up the Leven estuary, one of the series of north-and-south faults previously mentioned.

(2) The Furness District between the Duddon and the Leven Estuaries.

The beds, on the whole, resemble those of the Grange District, and include the succession from the *Seminula-gregaria* Sub-zone to the Upper *Dibunophyllum* Sub-zone. The country is drift-covered, and very few natural exposures of the lower zones occur. The central portion between Great Urswick, Stank, and Dalton is considerably faulted, and the limestones here and farther west are much altered and impregnated with hæmatite. The points of special interest in the district are:—

1. The presence of conglomerate and shales at the base of the succession in the north-western border between Marton and Elliscales, representing the *Athyris-glabristria* Zone of the type-districts.
2. The excellent development of the lower portion of the *Michelinia* Zone in the neighbourhood of Elliscales, and the presence of exposures showing the relationship of the upper and lower portions of this zone.
3. The fine series of exposures of the *Nematophyllum-minus* Sub-zone in the Longlands quarries.
4. The presence of the Southern or Kirkby Lonsdale facies of the Upper *Dibunophyllum* Sub-zone.

The *Athyris-glabristria* Zone.—The lowest beds consist of a conglomerate, overlain by calcareous shales and limestones which crop out between Marton and Elliscales. These are not well exposed at the present time; but a complete section of the beds, from the Silurian to the summit of the *Michelinia* Zone, can be examined in a core from an old boring near Maidenlands Quarry. This boring, which was carried to a depth of 168 feet, shows a thickness, from the base to a level somewhere below the summit of the *Michelinia* Zone, of about 150 feet. The lower half of this core, judging from the character of the rock, appears to belong to the upper portion of the *A.-glabristria* Zone. The presence of a basal conglomerate, which occurs in several layers in a red sandstone, is an interesting feature of the section, as no such basement-beds occur elsewhere in the Furness, Grange, or Arnside Districts. West of Elliscales, exposures of these lowest beds occur near the tramway-cutting, and on the east side of Elliscales Quarry. Specimens of *Carruthersella compacta* have been collected from the latter exposure, showing the analogy of these beds with the Meathop dolomites. On the east side of the Furness District two outcrops of the *A.-glabristria* Zone occur. The northernmost of these forms a small outlier resting upon the Silurian at Ashes Point, on the western shore of the Leven estuary. The small thickness exposed belongs to the *Seminula-gregaria* Sub-zone, and doubtless represents the upper portion of this zone at Meathop. A little farther south, the beds which form the base of the escarpment west of Plumpton Hall appear to belong to the same horizon.

The *Camarophoria-isorhyncha* Sub-zone is well exposed in the quarries at Elliscales, where some 20 or 30 feet of the lower portion of the *Michelinia* Zone are seen. The rock is a compact grey limestone, and contains very large examples of *Michelinia*

grandis; they are associated with *C. isorhyncha*, *Syringopora*, and *Cyathophyllum* cf. *multilamellatum*. The overlying beds of the Upper *Michelinia* Zone crop out on the other side of the Dalton road, where they are exposed in a small quarry and contain the usual Arnside species, including *Caninia cylindrica*.[1]

The beds of the Upper *Michelinia* Sub-zone extend southwards to the neighbourhood of Dalton, and are also met with in the spoil-heap from the mine-shaft close to the cross-roads, about a quarter of a mile south of Lindale Cote. The shale taken out of the shaft contains abundant remains of *Zaphrentis koninckı* and other characteristic fossils. It is, nevertheless, probable that the beds are here overlain by the Gastropod Beds; but the surface is drift-covered. On the east side of the district good exposures occur in the large quarry at Gascow, and again nearer the coast in the outlier near Plumpton Hall. At both these localities the fauna appears to be normal. In the Gascow section the beds come to the surface in a dome-shaped inlier, only the upper portion of the zone being exposed near the floor of the quarry; the fauna is especially rich in specimens of *Zaphrentis koninckı* and *Z. enniskilleni*, while the *Clisiophyllum-multiseptatum* Band is also well developed. M'Coy's interesting form *Diphyphyllum dianthoides* also occurs in both these sections.

The Gastropod Beds call for no comment, and succeed the *Michelinia* Zone in the sections at Gascow and Plumpton; they also occupy a considerable area to the south and east of Lindale.

The *Nematophyllum-minus* Sub-zone is well exposed in places, especially in Longlands Quarry, which is chiefly excavated in these beds. Quarries have also been opened at this horizon near the cross-roads on the west side of Birkrigg Common, and the rocks crop out at the surface between this latter exposure and Gascow Quarry.

The Lower *Dibunophyllum* Sub-zone forms the high ground on the east side of the Urswick-Tarn Fault. It occupies the whole of Birkrigg Common, and also the coast-line from Conishead Priory to Baycliff and Aldingham; while the base of the zone forms an irregular outcrop from Bighead Wood, round the west side of Birkrigg Common, to Scroggs Close and Baycliff. Chapel Island also affords a good exposure of the rocks of this zone, which include the 'Stick' bed and the beds of pseudo-breccia (see Pl. XLVI, fig. 2, facing p. 518).

On the west side of the Urswick-Tarn Fault these beds occupy the high ground immediately west and south-west of Little Urswick. South of Stainton the zone is faulted back to the west by a north-west and south-east fault, and the 'spotted' beds characteristic of

[1] I have to thank Mr. Mellon, the manager of the Elliscales Quarries Syndicate Ltd., for his kindness in allowing me to examine this section, and for the gift of the fine specimen of *M. grandis* exhibited in the collection at University College (London).

the zone are seen in the quarry half-a-mile west of Stainton on the road from Dalton to Dendron.

The *Cyrtina-septosa* Band is exposed in the old quarries at Little Urswick, on the shore below Sea Wood and on Chapel Island.

The Upper *Dibunophyllum* Sub-zone occupies much of the district to the south of Little Urswick, between Hawkfield and Gleaston. The development here resembles the southern or Kirkby Lonsdale type, and the limestone near the base contains the following species :—

Aulophyllum cf. *pachyendothecum* Thomson.
Caninia cf. *subibicina* M'Coy.
Dibunophyllum turbinatum M'Coy.

Athyris expansa (Phill.).
Athyris planosulcata (Phill.).
Cliothyris royssi (L'Éveillé).
Camarophoria crumena (Mart.).
Chonetes laguessiana de Kon.
Leptæna analoga Phill.
Martinia glabra (Mart.).
Productus cf. *auritus* Phill.
Productus costatus Sby.
Productus fimbriatus Sby.
Productus giganteus Mart.
Productus latissimus Sby.
Productus pugilis Phill.
Productus scabriculus Mart.
Productus semireticulatus Mart.
Productus cf. *spinulosus* Sby.
Productus cf. *youngianus* Dav.
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Spirifer bisulcatus Sby.
Spirifer pinguis Sby.
Spirifer triangularis Mart.
Spiriferina octoplicata Sby.

Phillipsia eichwaldi Fischer.

VII. The Westmorland Pennines and the Middleton-in-Teesdale District.

A portion of the Pennine escarpment east of Appleby lies in the county of Westmorland. This Carboniferous tract is separated from the Shap District by the Permian and Triassic rocks which occupy the Vale of Eden, and by the Pennine Fault.

For purposes of comparison with the rest of the North-Western Province, the lower beds of the Pennine escarpment which are exposed at intervals between Great Rundale Beck and Great Musgrave Scar have been especially studied; the rocks here appear to include the lowest horizons met with along the escarpment, and are less disturbed by faults than those which occupy the country farther south.

The higher beds in the same area have also been examined, but the results recorded here are limited to a comparison with the general sequence already described; no attempt is made to give an exhaustive account of the fauna of the Yoredale rocks of the northern portion of the Pennine Chain.

The succession in Upper Teesdale includes a series of marine beds in the neighbourhood of Botany to the south of Middleton, mapped by the officers of the Geological Survey as Millstone Grit. Though not in Westmorland, the series forms a direct continuation of the Westmorland succession, and is included here, as it is the only district where a sequence from the Lower to the Upper Carboniferous rocks can be readily obtained in the North-Western Province.

Comparison with the Type Districts.

The chief noteworthy features are :—

1. The absence of the Shap Dolomite Series below the *Thysanophyllum* Band, that is to say, of practically the whole of the *Athyris-glabristria* Zone: a fact which points to the submergence of the area now occupied by the northern portion of the Pennine Chain, at a considerably later date than the Shap and Ravenstonedale Districts.
2. The presence of a series of fossiliferous mudstones and pebble-beds at the base of the succession, overlain by barren sandstones. These represent all the beds from the *Thysanophyllum* Band up to the middle of the *Nematophyllum-minus* Sub-zone.
3. The fuller development of the Yoredale rocks, which in the Middleton District approximates to the normal development of this series in Wensleydale.
4. The presence of a series of impure cherty limestones and calcareous shales (the Botany Beds), which occur high up in the Millstone Grit Series of the Geological Survey map, and contain abundant remains of *Dibunophyllum muirheadi* and *Phillipsastræa radiata*, associated with a fauna which closely resembles that of the *Cyathaxonia* Beds of D_3 in Derbyshire.
5. The presence of an intrusive sheet of dolerite, the Whin Sill, which has altered the rocks locally to such an extent, that the correct determination of the fossils in the beds in contact with it is often rendered impossible.

The Basement Series.—These beds are best exposed in the neighbourhood of Roman Fell, and the whole series is mapped by the officers of the Geological Survey as the 'Roman-Fell Beds.'[1] On the Geological Survey map, however, a patch of pebble-beds which occurs on the west side of Roman Fell is separated as an underlying series called 'Basement Beds' (red conglomerate).

It is extremely doubtful, however, whether the conglomerates seen on Roman Fell itself really belong to the same series as the fossiliferous grits and pebble-beds which crop out east and south of Roman Fell. If they do, they must certainly lie below these latter beds; but it is much more probable that they represent an older series, and are contemporaneous with the Polygenetic Conglomerate of the Sedbergh and Ullswater Districts: as, however, they have yielded no fossils of Carboniferous age, they need not be further discussed in detail. One word, nevertheless, may be said as regards their relation to the fossiliferous basement series which will be next described. The Roman-Fell Beds are coloured as Basement Carboniferous on the Geological Survey map, and are shown passing conformably up into the Melmerby-Scar Limestone Series of Long Fell on the east; this mapping does not appear to be correct, as one fault, at least, separates Roman Fell from the Carboniferous Limestone Series of Long Fell. This fault, which is marked by a row of potholes (fig. 3, p. 536), passes close to the old sheepfold near the summit of the col between Roman Fell and Long Fell. From the top of the col it runs nearly due south towards the Druid's Temple, where it apparently joins the main, or outer, Pennine Fault. There can be no doubt regarding the existence of this fault, for it brings the Bryozoa Band (B, fig. 3) on the east, which crops out at a height of 1750 feet, below the level of the highest beds of the Roman-Fell Conglomerate on the west, which rise to 1946 feet O.D.,

[1] New Series, Sheet 31 (Brough-under-Stainmoor).

thus cutting out the whole of the grit-and-sandstone series and the *Nematophyllum-minus* Band which are exposed below in Swindale Beck. This unmapped fault is, indeed, of much greater importance than that which runs along the upper part of Swindale Beck, marked on the Geological Survey map. It appears to be the southerly continuation of the inner Pennine Fault, which is seen crossing Scordale Beck immediately north-north-west of the summit of Roman Fell. From here it curves round under the screc-covered northern slope of Roman Fell to the col already mentioned. The Roman - Fell Beds are therefore entirely cut off by this fault from the Carboniferous succession on the east and south. (See fig. 3.)

Fig. 3.—*Geological map, on the scale of 1 inch to the mile, or 1 : 63,360.*

[ooo = Potholes. The suggested fault (broken line) has been erroneously shown west of the potholes, instead of east of them. NM = *Nematophyllum-minus* Sub-zone; Th = *Thysanophyllum* Band; S & Sy = Brownber Pebble-Bed with *Syringothyris*; B = Bryozoa Band; LF = *Lonsdalia-floriformis* and Nodular *Girvanella* Band; D_1 = Lower *Dibunophyllum* Sub-zone. The thick black bands indicate the course of the Whin Sill. The heavily dotted area represents the Roman-Fell Conglomerate; the lightly dotted areas represent the fossiliferous grits and pebble-beds.]

The beds, again, on the two sides of the fault are totally different; for, whereas the pebbles in the Roman-Fell Conglomerate are largely composed of Lower Palæozoic rocks, those in the Carboniferous pebble-beds on the east are almost entirely composed of quartz. Again, the matrix in the Carboniferous pebble-beds is marked by well - developed oolitic structure; while no such structure is met with in that of the Roman-Fell Beds.

Lastly, whereas Carboniferous fossils, including *Syringothyris cuspidata* are not uncommon in the oolitic pebble series (S & Sy, fig. 3) on the east, no fossils beyond those contained in the pebbles derived from Lower Palæozoic rocks have ever been met with in the conglomerate of Roman Fell.

On the north side of Roman Fell the lowest Carboniferous deposits are exposed in Scordale and Swindale Becks, and close to the junction of these streams they are brought down against the Skiddaw Slates by the Inner Pennine Fault.

In Scordale Beck above Hilton, on the right bank of the stream, chocolate-coloured grits with green streaks occur interbedded with fine conglomerates and green and red shaly sandstones, containing pebbles of the underlying Silurian rocks. The deposit appears to be completely unfossiliferous, but the outcrop is buried under landslips and scree-material. In Swindale Beck, which drains the north-eastern flank of Roman Fell, this series of basement beds is better exposed, and consists of false-bedded, green, pebbly grits containing fragments of felsite, Skiddaw Slate, etc. These are overlain by yellow concretionary sandstones passing upwards into a coarse conglomerate, which gives rise to a small waterfall in the beck.

The *Athyris-glabristria* Zone.—In Swindale Beck, about two-thirds of a mile above its junction with Scordale Beck, a fossiliferous bed crops out on the left bank of the stream (S in fig. 3, p. 356). This outcrop is of especial interest, as it is the only fossiliferous exposure met with in the beds below the Melmerby-Scar Limestone north of Roman Fell. The rock is predominantly a crinoidal limestone stained by limonite; some of the layers, however, consist of a calcareous grit enclosing small quartz-pebbles and crinoid-ossicles. This deposit appears to be a beach-formation, most of the fossils being fragmentary, and some of them probably derived. A few feet higher in the series, and farther up the stream, a calcareous breccia occurs on the same bank of the stream, nearly opposite Swindale Crag; this contains a similar fauna, but in a still more fragmentary condition. The most abundant fossil in both exposures is *Syringothyris cuspidata*. The following is the list of species obtained from these two exposures:—

Syringopora sp.

Athyris glabristria (Phill.).
Camarophoria isorhyncha (M'Coy).
Productus cf. *punctatus* Mart.
Productus cf. *hemisphericus* Sby.
Reticularia lineata (Mart.).
Rhipidomella michelini (L'Éveillé).
Schellwienella cf. *crenistria* (Phill.).
Seminula cf. *ambigua* (Sby.).
Spirifer furcatus M'Coy.
Syringothyris cuspidata (Mart.).

Bellerophon sp.

This assemblage recalls that found in the Brownber Pebble-Bed and in the *Spirifer-furcatus* Band of the type-districts. The presence of *Syringothyris cuspidata* and *Athyris glabristria* is sufficient evidence that the deposit must underlie the *Michelinia* Zone; for, although rare in the North-Western Province, *S. cuspidata*, as noted above, occurs only in beds at and below the base of that zone. Again, the bed resembles very closely the *Syringothyris* Grit at the base of the *Michelinia* Zone under Cunswick Scar in the Kendal District, and may, therefore, represent, in part, the Brownber

Pebble-Bed of the type-districts. If this view be correct, the sandstone of Swindale Crag, which underlies the Melmerby-Scar Limestone, must represent an attenuated development of the Orton Sandstone of the Shap District.

In High-Cup Gill these beds are not well exposed; but in Great Rundal Beck, farther north, fragments of *Syringothyris cuspidata* have been collected from the hard gritty beds which crop out below the Melmerby-Scar Limestone on the south side of the beck, and these beds may, therefore, be correlated with the fossiliferous rocks of Swindale Beck. South of Roman Fell these beds are much obscured by superficial deposits: two interesting exposures, however, do occur, one in Highclose Sike and the other in Dobbyhole Sike (Th & Sy in fig. 3, p. 536). In Highclose Sike the stream has cut down through an anticlinal fold, exposing 30 or 40 feet of calcareous sandstones, mudstones, and pebble-beds. In the lower part of the exposure, below the wood, the stream runs along a bed of hard calcareous mudstone. This bed is much jointed, and weathers into nodular concretionary masses; it contains a few fragmentary fossils. The overlying beds are well exposed on the left bank of the stream below the old limekiln, where they consist of calcareous grits and pebble-beds and layers of dun-coloured impure limestone. The latter have yielded the following fossils:—

Productus cf. *corrugato-hemisphericus* Vaughan.
Rhipidomella michelini (L'Éveillé).
Rhynchonella cf. *fawcettensis* sp. nov.
Schellwienella cf. *crenistria* (Phill.).
Syringothyris cuspidata (Mart.).

The specimens of *S. cuspidata* are found in the upper pebble-bed, and are, as usual, in a somewhat fragmentary condition. An interesting feature of this pebble-bed is the occurrence of layers of coarse oolite, forming the matrix in which the white quartz-pebbles are embedded. This is by far the best-developed oolite met with in the North-Western succession, and the bed resembles very closely the Brownber Pebble-Bed already described from the type-districts. The presence of this oolitic pebble-bed affords valuable evidence as to the relative date of the submergence of the area now occupied by this portion of the Pennine Chain. The submergence must have occurred about the period when the *Thysanophyllum* Band was being deposited farther west: that is to say, during the deposition of the C_2 beds in the South-Western Province. This view is confirmed by a study of the section in Dobbyhole Sike. Here the rocks consist of impure gritty and bituminous limestones containing a few fossils, in a bad state of preservation. The fauna is of rather an ambiguous character, but among others occur specimens of *Thysanophyllum pseudovermiculare*, which appear to be unrolled, and even if derived must have grown somewhere in the immediate neighbourhood.

The presence of quartz-pebbles at the horizon of the Brownber Beds all along the Shap-Ravenstonedale escarpment, and their absence from this horizon farther west, are very interesting features which have been mentioned already, and appear to show that the

land which supplied the quartz-pebbles lay to the east of the type-districts. The most likely source of these pebbles would appear to be the quartz-veins of the Skiddaw Slates and other Lower Palæozoic rocks, a fragment of which is exposed in Brownber Pike.

We cannot, therefore, go far wrong in correlating the beds which underlie the Melmerby-Scar Limestone in the Pennine District with the succession from the *Thysanophyllum* Band to the base of the *Nematophyllum-minus* Sub-zone in the type-districts.

The *Nematophyllum-minus* Sub-zone.—The Melmerby-Scar Limestone, which overlies the basement sandstones and pebble-beds described above, consists for the greater part of rocks belonging to the Lower *Dibunophyllum* Sub-zone; but a small thickness at the base represents the *N.-minus* Sub-zone, and the index-fossil, though not abundant here, can usually be found. The beds are exposed on the right bank of Scordale Beck, on Middle Fell, Middle Tongue, and elsewhere along the escarpment.

The associated fauna is similar to that already described in the neighbourhood of Shap, and calls for no special remark, though the *Cyrtina-carbonaria* Sub-zone has not been separated in this district. The beds, therefore, correspond closely with the Shap sequence from the Orton Sandstone upwards, and strengthen the view that the lower sandstone at Scordale Beck represents the Orton Sandstone.

The Bryozoa Band is well developed in this district, and good exposures occur near the col at the northern end of Long Fell, close to the old sheepfold east of the line of fault already mentioned (p. 535); indeed, it was in this district that the importance of this band was first recognized.

The rock here is composed of a shaly, grey, bituminous limestone, containing a rich fauna closely resembling that of the Bryozoa Band on Weather Hill, in the Shap District.

The Lower *Dibunophyllum* Sub-zone presents no unusual features; it appears, however, to be somewhat thinner than in the Western Districts. It forms the bulk of the Melmerby-Scar Limestone along the Pennine escarpment. The 'spotted' beds towards the summit of the sub-zone are especially well developed in Great Rundal Beck, behind Dufton Pike.

The Upper *Dibunophyllum* Sub-zone.—The Yoredale Beds are more fully developed here than in the Shap District. The base of the sub-zone is taken at the first sandstone above the Melmerby-Scar Limestone.

The *Lonsdalia* Beds are well exposed on the north side of Scordale Beck, in High-Cup Gill, and in Great Rundal Beck. In the first-named beck the base of the sub-zone lies above the Whin Sill, which is there intrusive in the Melmerby-Scar Limestone; but in High-Cup Gill the Whin Sill has risen in the series, and at High-Cup Nick lies near the base of the Tyne-Bottom Limestone. It is

interesting to note that the Nodular *Girvanella* Band, which is very characteristic of the base of the sub-zone elsewhere, is also present in this district. This sub-zone includes the beds from the summit of the Melmerby-Scar Limestone up to the top of the 'Jew' Limestone inclusive. The fauna is similar in all respects to that which characterizes the *Lonsdalia* Beds in the Shap District.

The *Saccammina* Band appears to be represented by the Tyne-Bottom Limestone, which is well exposed on the eastern flank of High-Cup Gill. Here, as in the Shap District, the horizon is marked by the abundance of *Productus edelburgensis*, associated with *Zaphrentis* aff. *constricta* Carr. MS.

The higher beds of the Upper *Dibunophyllum* Sub-zone, overlying the Tyne-Bottom Limestone, are much more fossiliferous than is the case in the Shap District; thus, in Great Rundal Beck, the shale overlying the Scar Limestone contains the following forms:—

Cyathaxonia cornu Mich.
Dibunophyllum muirheadi Nich. & Thomson.
Diphyphyllum sp. nov.
Zaphrentis costata M'Coy.

Cyathocrinus sp.
Platycrinus sp.

Fenestella membranacea (Phill.).
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
Fistulipora incrustans (Phill.).
Glauconome sp.

Lingula squamiformis Phill.
Orbiculoidea nitida (Phill.).
Cliothyris royssi (L'Eveillé).
Leptæna analoga Phill.
Pugnax pugnus (Mart.).
Rhipidomella michelini (L'Éveillé).

The presence of *Cyathaxonia cornu* at this horizon is of interest, and may possibly indicate that we have here reached the base of the *Cyathaxonia* Beds of Dr. Sibly's Derbyshire sequence. At the same time, it must be admitted that *Cyathaxonia* is rare in the Pennine Area, and has not been definitely met with in the other districts.

The Middleton-in-Teesdale District.

In Upper Teesdale the local base of the Carboniferous is exposed between High Force and Cauldron Snout. Here a shaly conglomerate crops out under Falcon Clints, on the left bank of the Tees above Widdybank Farm; it cannot lie far above the Lower Palæozoic floor, and is represented on the Geological Survey map as resting on felsite and Ordovician slates north of the farm. Above this conglomerate occur grey shales which have been much metamorphosed by the intrusion of the Whin Sill, with the production of the interesting pisolitic structures described by Mr. Hutchings.[1] The base of the overlying limestone has also been much metamorphosed with a development of garnets.

[1] Geol. Mag. dec. 4, vol. ii (1895) pp. 122 *et seqq.*

The shales and basement-beds are apparently unfossiliferous, but specimens of *Nematophyllum minus* altered into saccharoidal limestone have been collected from the overlying limestone. This indicates that the base of the Lower Scar Limestone in Teesdale lies, as in the case of the Pennine escarpment, in the *N.-minus* Sub-zone.

The Lower *Dibunophyllum* Sub-zone is found overlying the Whin Sill on Widdybank Moss, but is also much metamorphosed. Below High Force no further exposure of these lower beds is seen, the Yoredale Beds being here brought in by the Burtreeford Fault, so that they occupy both sides of the valley as far as Middleton-in-Teesdale.

The Upper *Dibunophyllum* Sub-zone, composed of the Lower Yoredale limestones up to the Great Limestone, contains a fauna similar to that already described. Some of the intercalated shales are rich in fossils. A good exposure of a fossiliferous shale occurs above Holm-Road Bridge in Huddeshope Burn. This appears to be near the horizon of the Four-Fathom Limestone, and is rich in the remains of brachiopoda and bryozoa.

Fauna.

Aulophyllum cf. *pachyendothecum* Thomson.

Cystodictya sp.
Fenestella membranacea (Phill.).
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
Goniocladia cellulifera Eth. jun.
Pinnatopora sp.
Polypora sp.
Rhabdomeson sp.

Orbiculoidea nitida (Phill.).

Cliothyris royssi (L'Éveillé).
Productus cf. *edelburgensis* Phill.
Productus longispinus Sby.
Productus punctatus Mart.
Rhipidomella michelini (L'Éveillé).
Spirifer bisulcatus Sby.

Loxonema sp.
Murchisonia sp.

Orthoceras sp.

Phillipsia farnensis Tate.

The higher Yoredale Beds, from the Scar Limestone upwards, are best studied in the sections and quarries exposed in the Huddeshope and Snaisgill valleys north of Middleton, and along the road between Middleton and Brough. The beds are throughout characterized by the abundance of *Dibunophyllum muirheadi*. In the Great Limestone, in addition to *Productus giganteus*, *Pr. latissimus*, and other characteristic Yoredale forms, we meet with a large columnar form of *Lonsdalia* which appears to differ specifically from *L. floriformis* of the *Lonsdalia* Beds at the base of the zone. Many of the shales are rich in lamellibranchs, and casts of brachiopods occur frequently in the sandstone layers. One such band crowded with *Spirifer* cf. *bisulcatus* forms the highest fossiliferous horizon of the Yoredale Series in Teesdale, and the same band appears to extend into the upper part of Weardale.[1]

[1] Casts of this species show, along the inner margin of the hinge-line of the pedicle-valve, a row of pits which must represent, either casts of spine-bases, or a row of granules that forms an articulating surface between the two valves.

The Botany Beds (*Phillipsastræa* Band).

These deposits comprise impure limestones and calcareous shales about 20 feet thick, intercalated in the series of grits and shaly sandstones which are coloured as Millstone Grit on the Geological Survey map. The beds lie some distance above the base of this series, and occupy a tract extending for 2 miles in a general east-and-west direction on Hurdorthwaite Moor, south of Botany Farm. They are repeated by a strike-fault with a southward upthrow, which causes an extension of the outcrop round the south of the moor and affords additional exposures.

The beds are well seen in several old quarries at Scoletree, Howgill Head, and Greenhill. They consist of a few feet of compact crystallized limestones at the base, which is overlain by some 10 to 15 feet of impure calcareous and ferruginous shales. The shales are hard and nodular in places, but present a curious cellular appearance seemingly due to partial solution. Cherty bands occur in irregular patches; these are almost confined to the upper layers, and yield the chief examples of *Phillipsastræa*. The corals are often replaced by silica, which in thin sections exhibits marked spherulitic structure. The beds are of considerable interest, as they represent the highest horizon in the North-Western Province containing a typical Lower Carboniferous marine fauna.

Fauna.

**Hyalostelia parallela* M'Coy.

Dibunophyllum muirheadi Nich. & Thomson.
Lithostrotion junceum (Fleming).
Lithostrotion portlocki (Bronn).
Michelinia cf. *tenuisepta* (Phill.).
**Phillipsastræa radiata* (Woodward).

Archæocidaris sp.

Spirorbis sp.

**Anisotrypa* sp.
Fenestella membranacea (Phill.). Very abundant.
Fenestella nodulosa (Phill.).
Fenestella plebeia M'Coy.
(?) Goniocladia (casts only) Eth. jr.
Pinnatopora sp.
Polypora dendroides M'Coy.

Lingula cf. *squamiformis* Phill.
Athyris cf. *ambigua* (Sby.).
Cliothyris royssi (L'Éveillé).
Dielasma hastatum (Sby.).
Leptæna analoga Phill.
**Productus aculeatus* Mart.
Productus costatus Sby.
Productus elegans M'Coy.
Productus cf. *longispinus* Sby.
Productus martini J. de C. Sby.
Productus plicatilis J. de C. Sby.
Productus cf. *pugilis* Phill.
Productus aff. *punctatus* Mart. (with more numerous bands than the typical *punctatus*).
Productus punctatus (typical) Mart.
Productus scabriculus Mart.
Productus semireticulatus (typical) Mart.
Productus cf. *sulcatus* J. de C. Sby.
**Schellwienella radialis* (Phill.).
Schizophoria resupinata (Mart.).
Spirifer bisulcatus Sby.
Spirifer triangularis Mart.

Aviculopecten dissimilis (Fleming).
Conocardium aliforme Sby.
Sanguinolites cf. *monensis* Hind.

Capulus sp.
Dentalium sp.
Loxonema sp.
**Naticopsis* cf. *globosa* Hœninghaus.
Pleurotomaria sp.

Orthoceras sp.
**Prolecanites (?)* fragment.

Petalodus acuminatus Ag.

The fossils are well preserved in calcareous nodules in the shale, and the fauna may be compared with that of D_3 of Derbyshire; some of the species (marked with an asterisk) have not been met with elsewhere in the area described in the present paper.

Among the corals, an interesting occurrence is that of *Dibunophyllum muirheadi*, showing the persistence of this form throughout the Yoredale Series of the Pennine District; it enters near the summit of the *Lonsdalia-floriformis* Sub-zone, is found plentifully in several of the higher Yoredale Limestones, especially the 'Great' Limestone, and is still abundant in the Botany Beds. Another interesting form, practically limited to this horizon, is *Phillipsastræa radiata*, which occurs somewhat abundantly in the upper chert-bearing portion of the deposits. I have never found it *in situ* at any other horizon, but two specimens were collected as loose blocks. One of these was found resting upon the Tyne-Bottom Limestone in High-Cup Gill, and, as the specimen was quite angular and unworn, may possibly have been derived from one of the overlying Yoredale limestones close by; the other was found washed out of the drift-deposits in Ravenstonedale, the coral being preserved as a cast in a hard gannister-bed which must have been derived from the higher Yoredale or Millstone-Grit beds of the Pennine Chain on the east or north-east. Outside the North-Western Province *Phillipsastræa* is also apparently characteristic of the higher beds of the *Dibunophyllum* Zone.

Many of the brachiopods are also characteristic of a high horizon in Derbyshire; and some species as, for instance, *Schellwienella radialis*, have not been met with at a lower horizon in the North-Western Province.

So far as I am aware, this is the highest truly marine fauna yet met with in the North of England. The appearance of this fossiliferous limestone deposit, overlying a considerable thickness referred to the Millstone Grit by the officers of the Geological Survey, is of some interest. The fauna cannot be considered as a remnant of the local Yoredale fauna that collected here before being completely exterminated: for, not only is the fauna as a whole not characteristic of the underlying beds, but the arenaceous character of the deposit immediately below makes this hypothesis untenable.

These deposits must have resulted from a local depression, which carried the sea-floor temporarily beyond the area of mechanical deposition, and opened a communicating channel with the deeper sea that still existed on the south or west. The limited area now occupied by the limestone deposit near Botany would seem to point to the west as the direction whence this fauna migrated: since, in that direction, denudation has removed all the upper beds of the *Dibunophyllum* Zone, and also the Millstone Grit; and so there is nothing to prevent the deposit now described from having previously extended in that direction. On the north-west and south, on the other hand, there is a continuous upward sequence into the Coal Measures; but no limestones representing these beds occur elsewhere in Durham or Yorkshire north of the Craven Faults. On

the whole, then, we can best regard the 'Botany Beds' as the result of a depression which temporarily established communication with the deeper water lying on the west or south-west.

This view receives support from the character of the brachiopod fauna in the highest limestone layers in the Kirkby Lonsdale and Furness Districts, many of the species being identical with those found in the Botany Beds. The fossiliferous shale, shown on the Geological Survey map as occurring well up in the Millstone Grit in the district south and south-east of Kirkby Lonsdale,[1] would appear to mark the southern shallow-water continuation of this deposit.

A small outlier of these shales is situated in the Kirkby Lonsdale District, on the northern bank of the River Lune at its junction with the River Wenning.[2] Farther south-east in the Bowland District the band is still found occupying the same position in the Millstone Grit, overlying the Pendleside Series of Dr. W. Hind. If this correlation of the Botany Beds with these fossiliferous shales be correct, it affords additional evidence, if it were necessary, of the Lower Carboniferous age of the Pendleside Series, for the fauna of the Botany Beds which are thus shown to overlie the Pendleside Series is, as already pointed out, characteristic of the highest limestones of Derbyshire.

VIII. Correlation with the South-Western Province and other Areas.

The correlation of the zones described in the foregoing pages with those established by Dr. Vaughan in the Bristol District is set forth in the last column of the table (p. 547). In comparing the different horizons in the two districts, it will be best to begin with the Lower *Dibunophyllum* Sub-zone, which, as already stated, appears to be identical in the two provinces. Thus, in both provinces, this horizon is characterized as a rule by fine-grained crystalline limestones containing beds of pseudobreccia typically near the summit; while the fauna is characterized by the abundance of specimens of *Dibunophyllum* ϕ, *Cyathophyllum murchisoni*, and *Carcinophyllum* θ. This similarity is undoubtedly due to the fact that it was during the period when these beds were being deposited that the greatest submergence in Lower Carboniferous times occurred in Britain.

The beds immediately overlying the Lower *Dibunophyllum* Sub-zone in the North-Western Province can also be readily correlated with the *Lonsdalia* Beds of the South-Western Province, as they are characterized by the presence of *Lonsdalia floriformis*, *Cyathophyllum regium*, and *Dibunophyllum muirheadi*, belonging to Dr. Vaughan's group of Dibunophyllids in the stage ψ. The Yoredale beds above the 'Scar' Limestone of the Pennine District

[1] This bed is coloured green, and in the legend stated to be fossiliferous; but, unfortunately, no fossils from it have been preserved in the Museum of Practical Geology, Jermyn Street.

[2] Mr. C. H. Cunnington has obtained numerous crushed specimens from this exposure, referable apparently to *Posidoniella lævis*, and three species of Goniatites.

would then correspond to horizon ϵ and some part of the 'Millstone Grit' of the Bristol Area.

The limiting line between the beds known as D_2 and D_3 in the Midland and other areas is by no means clearly defined in the North-Western Province, partly on account of the barren character of the higher limestones in the Shap District, and partly on account of the complete absence of fossils from the whole of the upper portion of this series in the Kirkby Lonsdale and Furness Districts. It is true that, in the Pennine District, one or two specimens of *Cyathaxonia cornu* have been collected from the shale underlying the Scar Limestone; but this circumstance does not entitle us to correlate the beds above this horizon with the *Cyathaxonia* Beds of the Midlands.[1]

With regard to the highest fossiliferous marine limestone which occurs at Botany, there can be no doubt that it must be correlated with an horizon well up in the *Cyathaxonia* Beds of the Midland area, such forms as *Schellwienella radialis*, *Productus aculeatus*, *Spirifer triangularis*, and *Phillipsastræa*, together with several others, never occurring below the summit of the *Lonsdalia* Beds in the North-Western Province.

With regard to the beds underlying the *Dibunophyllum* Zone, the *Productus-corrugato-hemisphericus* Zone appears to represent closely the *Seminula* Zone of Dr. Vaughan's Bristol paper[2]; as, however, the upper and lower limits are not absolutely certain, it will be best at present to avoid absolute correlation with this zone. The name '*Seminula* Zone' also, is scarcely applicable to this division in the North-Western Province, although *Seminula ficoidea* is present occasionally in the zone. This genus is, however, much more characteristic of the upper portion of the *Athyris-glabristria* Zone in the North-Western Province, where it is represented by abundant specimens of *S.* aff. *ficoidea* together with *S. gregaria*.

Of the three portions into which the zone is divided, the Gastropod Beds, which form the lower portion, appear to be closely equivalent to the S_1 beds of the Bristol Area, while S_2 is represented by the *Cyrtina-carbonaria* and *Nematophyllum-minus* Beds of this classification.

The *Michelinia* Zone has been considered by me to represent generally C_2 of the South-Western Province, the upper limit being taken at the *Clisiophyllum-multiseptatum* Band, above which the first specimens of *Lithostrotion* occur; but the exact horizon where the base of C_2 should be drawn in Westmorland is not easy to fix. In the type district the base of C_2 is taken at the Oatmeal Bed in Docker Beck, and this corresponds with the *Spirifer-furcatus* Band of the Arnside and Grange Districts. This will throw the beds between the *Camarotœchia-proava* Band and the *Thysanophyllum* Band inclusive, into C_1 of the Bristol Area. The lower beds at Shap Abbey and Stone Gill contain a form of *Athyris glabristria* (near *A. lamellosa*), which, Dr. Vaughan informs me,

[1] This view has been arrived at after conference with Dr. Sibly.

[2] Q. J. G. S. vol. lxi (1905) p. 194.

is characteristic of Z–C in the Bristol, Malahide, and Tournai areas. The lowest layers, therefore, containing the *Vaughania-cleistoporoides* Band must be provisionally correlated with Z–C of the South-Western Province.

The lowest fossiliferous horizon in the North-Western Province, found in Pinskey Gill (Ravenstonedale), contains a somewhat unique fauna. The characteristic *Spirifer* appears to be unknown in the Lower Carboniferous deposits of the Bristol District. The casts of the little *Camarotœchia*-like brachiopod bear a distinct resemblance to *C. mitcheldeanensis*, but are in too imperfect a state of preservation for exact determination. It will be best, therefore, for the present to leave the correlation of these beds as an open question, merely suggesting that they probably represent some portion of the *Zaphrentis* Zone of the Bristol sequence, since they underlie the conglomerate which forms the base of the Z–C beds mentioned above.

[Since this paper was read before the Society, I have had the pleasure of going over a good deal of the ground in the Shap and Ravenstonedale Districts with Dr. Vaughan, Mr. E. E. L. Dixon, and Mr. R. G. Carruthers, when special attention was given to the correlation of the beds with those of the South-Western Province. At the conclusion of the visit, Dr. Vaughan expressed himself in general agreement with the correlation set forth in the table on p. 547. He would, however, not only include the *Thysanophyllum* Band in C_2, but would extend that sub-zone downwards to the top of the Algal Limestones. Although only a small thickness of beds is involved, the change is important, as it throws the *Syringothyris-cuspidata* Beds into C_2, instead of C_1, where the index-fossil occurs typically in the Bristol District.

Mr. Dixon, while recognizing that the fauna of the *Solenopora* Sub-zone has affinities with that of C_1, considers that the physical evidence is in favour of his original view that submergence in the northern area did not take place until deposits of C_2 age were being laid down in the South-Western Province; his view will be found in the discussion published at the end of this paper (p. 585).]

Correlation with Northumberland.

The classification described in this paper can also be broadly applied to the Lower Carboniferous succession in Northumberland and North Cumberland, and by this means it is possible to establish with some degree of certainty the equivalents, in Northumberland, of the Bristol Zones. I have already given a general comparison elsewhere.[1] More recent work in Cumberland has shown that several of the horizons established in Westmorland are also clearly recognizable in the North Cumberland and Border Districts; but the detailed investigation of the succession is not yet complete. Mention may be especially made of the important development of algal limestones in North Cumberland at an horizon equivalent to that of the *Solenopora* Beds of Shap; while other bands also present in both districts are included in the accompanying table.

[1] 'Geology in the Field' (Jubilee vol. Geol. Assoc.) pt. iv (1910) p. 683.

North-Western Province.			Northumberland and North Cumberland.	S.W. Province and Midlands.
		Botany Beds (*Phillipsastræa* Band).	Millstone Grit.	D_3.
Dibunophyllum Zone.	Upper Sub-zone.	Upper Yoredale Beds. Dy.	BERNICIAN. Beds above the Acre Limestone. Dy.	D_2.
		Lower Yoredale Beds. *Saccammina* Band	...Acre Limestone.	
		Lower Yoredale Beds. *Lonsdalia* Beds	...Eelwell Limestone.	
		Lower Yoredale Beds. Nodular *Girvanella* Band.	...Oxford Limestone with Nodular *Girvanella* Band.	
	Lower Sub-zone.	...*Cyathophyllum murchisoni*	Woodend or Four Laws Limestone. Dun or Redesdale Limestone with *Spiriferina laminosa*.	D_1
Productus-corrugato-hemisphericus Zone.	Upper Sub-zone.	Bryozoa Band with *Spiriferina laminosa*. *Nematophyllum minus*	Scremerston or Plashetts and Lewisburn Coal Series.	S_2.
	Lower Sub-zone.	...including the Ashfell & Orton Sandstone.	TUEDIAN.	S_1.
Michelinia Zone.	Upper Sub-zone.	...*Chonetes carinata* & Orton Sandstone.	Fell Sandstone, with fossil-bands in Cumberland yielding *Michelinia* and *Camarophoria isorhyncha*.	C_2
	Lower Sub-zone.	...*Camarophoria isorhyncha*		
Athyris-glabristria Zone.	Upper Sub-zone.	...*Seminula gregaria* with *Syringothyris cuspidata*. Algal Layer.	Cement-stones with *Syringothyris cuspidata* and *Mitcheldeania*. *Productus* Beds with *A. glabristria*.	C_1
	Lower Sub-zone.	...*Solenopora* Beds *Camarotœchia-proava* Band.	Lower Freestones of Northumberland, Algal Reefs of Bewcastle District, and *Camarotœchia-proava* Band of the Border.	γ Z (?)

I have already tabulated the Yorkshire equivalents in Geol. Mag. dec. 5, vol. iv (1907) p. 73.

IX. Summary and Conclusions.

Zonal Divisions.

The Lower Carboniferous rocks of the North-Western Province may be divided into a series of palæontological zones and sub-zones, set forth in the table (fig. 2) on p. 452, which, with the exception of the *Cyrtina-carbonaria* Sub-zone, have been recognized in all of the districts described.[1]

In the type-districts of Shap and Ravenstonedale a series of palæontological horizons or 'bands' have also been determined which are of great local value; the majority of these can be traced in the other districts whenever the same horizons are exposed. As examples, I may cite the *Chonetes*-aff. *comoides* Band at the summit of the Lower *Dibunophyllum* Zone; the *Camarotœchia-proava* Band, which is found throughout the Shap and Ravenstonedale Districts, and at Meathop in the Arnside District; the Algal Layer, which occurs at the base of the *Seminula-gregaria* Sub-zone, and extends throughout the type-districts, the Kendal and Arnside Districts, and as far west as Plumpton in the Furness District; and the *Thysanophyllum* Band, which forms a well-defined horizon throughout the type-districts, under Roman Fell in the Pennine District, in the Kendal District, and in the eastern portion of the Grange District. On the other hand, some bands (such as the Bryozoa Band, the *Saccammina-carteri* Band, and the *Daviesiella-llangollensis* Band) are limited to certain portions of the eastern districts.

Lithology.

The sea in which the Lower Carboniferous rocks of the North-Western Province were deposited does not appear ever to have reached a great depth, the majority of the beds being evidently laid down in shallow water. The period of greatest submergence occurred during the deposition of the upper portion of the *Productus-corrugato-hemisphericus* Zone and the Lower *Dibunophyllum* Zone.

The lithological characters which mark the different horizons are, as a rule, constant over large areas. Dolomites and porcellanous cementstones are characteristic of the *Athyris-glabristria* Zone, and locally also of the highest Yoredale limestones. This dolomitization was penecontemporaneous, as shown by a study of the dolomites in the Shap District. Occasionally, it would seem to have been selective: thus *Solenopora* and other calcareous algæ are usually quite unaffected, although they are typically associated with dolomitic deposits. Oolites are specially characteristic of the Brownber Pebble-Bed and of the beds immediately overlying it in the Eastern Districts; but thin bands of fine oolite occur also

[1] The *Cyrtina-carbonaria* Sub-zone cannot be clearly differentiated from the overlying *Nematophyllum-minus* Sub-zone in the Arnside, Grange, and Furness Districts.

locally at several other horizons, the nuclei of the oolitic granules being frequently quartz-grains.

Dark bituminous limestones occur universally at the base of the Upper *Dibunophyllum* Sub-zone, and are also found in many of the overlying Yoredale limestones. Pure white limestones are limited to the deeper-water deposits of the *Nematophyllum-minus* and the Lower *Dibunophyllum* Sub-zones. True crinoidal limestones are almost entirely absent, with the exception of the thin limestone which occurs in the Upper *Dibunophyllum* Sub-zone in the Kirkby Lonsdale District.

Calcareous mudstones are specially characteristic of the upper portion of the *Michelinia* Zone in the Western Districts, where that zone is most fully developed. Thin layers of 'china-stone' occur locally at two horizons: namely, near the base of the *Seminula-gregaria* Sub-zone, and in the Bryozoa Band immediately underlying the *Dibunophyllum* Zone. These layers are usually crowded with small spherical bodies, many of which appear to be identical with *Calcisphera fimbriata* (Williamson).[1] These are invariably associated with plant-remains at the upper, and with calcareous algæ at the lower, horizon. The deposits appear to represent a fine impalpable mud, laid down in the shallow but quiet waters of a lagoon or estuary.

Shales and sandstones are, in most districts, limited to the Yoredale rocks of the Upper *Dibunophyllum* Sub-zone. Spotted limestones and pseudobreccias are peculiar to the beds of the Lower *Dibunophyllum* Sub-zone, and are found in all the districts. The 'spotted' limestones occur typically at the base and summit of this zone, and appear to represent an incipient attempt at concretionary segregation of the coloured impurities. In a few cases, however, as at Great Rundal Beck in the Pennine District, where this structure is very marked, the spots are due to a definite separation of the calcareous constituents from the detrital sand-grains. The pseudobreccias are practically confined to the upper portion of this sub-zone, and are specially associated with the *Chonetes*-aff. *comoides* Band. They appear to owe their origin to the shrinkage of the deposit during consolidation, occasionally accompanied by the same tendency to incipient concretionary action as that which gave rise to the 'spotted' beds. They would seem to have been deposited under special conditions, involving a general elevation of the sea-floor.

The lithological conditions which characterize the different horizons are, on the whole, remarkably constant throughout the area; but three notable exceptions may be mentioned. The first is the important transgression of an arenaceous type of deposit across several of the faunal horizons that occurs in the Shap and Ravenstonedale Districts, traces of which can also be found in the Pennine District on the east and the Kendal District on the west. This sandstone episode, which begins at the base of the *Michelinia*

[1] Compare also *Sporocarpus elegans*.

Zone at Shap, does not make its appearance at Ravenstonedale until the middle of the Lower *Productus-corrugato-hemisphericus* Sub-zone; it also persists up to a higher horizon in the former district than in the latter. At the same time, the actual thickness of the sandstone series is greater in the southern than in the northern portion of the area. As a result of this incursion of arenaceous material, the normal faunas are very much reduced, or entirely absent from the horizon at which it occurs.

The second important change in the lithology of an horizon when traced laterally occurs in the Upper *Dibunophyllum* Sub-zone. This sub-zone presents two distinct facies, each of which has a separate geographical distribution: a northern and eastern facies, characterized by a Yoredale type of deposit, and consisting of a series of bituminous limestones, separated by shales and sandstones; and a southern and western facies (situated in the neighbourhood of Kirkby Lonsdale, Carnforth, and Gleaston), characterized by the absence of the typical series of Yoredale limestones, by the presence of a bed of true crinoidal limestone in the middle of the series, and by the local occurrence (in the upper part) of crystalline and brecciated limestones, which resemble the knoll-reef limestones of the Cracoe district and contain a similar fauna.

A third type of deposit, which is only met with at Botany, in the Middleton portion of the Pennine District, consists of a series of fine limestones and cherty calcareous shales lying high up in the Millstone Grit Series. These beds constitute an important fossiliferous deposit unknown elsewhere in the North of England, containing a fauna characteristic of the higher portion of the Derbyshire limestone-massif.

The Flora and Fauna.

Of the organisms which contribute to the deposits, corals and brachiopods are by far the most important, but foraminifera are present in nearly all the deposits, and are frequently abundant; ostracods and bryozoa are also locally plentiful in the more argillaceous layers.

One of the most interesting facts brought out by a microscopic examination of the rocks of this area is the important part played by calcareous algæ in the formation of the more compact and porcellanous layers of the deposit. The genus *Solenopora*, which occurs so universally in the lower portion of the *Athyris-glabristria* Zone, is of peculiar interest, not only on account of the part that it plays as a rock-builder, but also on account of the fact that it has not previously been recorded from any formation between the Ordovician and the Jurassic. Its discovery here assists, therefore, in bridging over the gap previously existing in the history of its vertical distribution. Another form, *Girvanella*, appears to have borne a large share in the formation of the nodular band so characteristic of the base of the Upper *Dibunophyllum* Sub-zone throughout

the North of England. Other interesting forms also occur which cannot be fully described here, although they contribute largely to the formation of the Algal Layer at the base of the *Seminula-gregaria* Sub-zone. With the exception of calcareous algæ, plant-remains are but sparingly represented; mention, however, may be made of *Archæosigillaria vanuxemi*, which was first described in Britain from the Shap District. So far as is known, this species is limited to the lowest zone, in which, however, it occurs at several horizons; associated with it, occasionally, are specimens of *Bothrodendron*.[1]

Siliceous organisms are on the whole rare, though some of the spherical bodies associated with *Calcisphæra* may perhaps come under the category of radiolaria, the siliceous skeleton of which has been subsequently replaced. Sponge-remains are occasionally found, and include examples of *Pemmatites*, together with two species of *Hyalostelia*. Chert is met with locally, especially in the higher portion of the *Dibunophyllum* Zone, but never in any great quantity; and true beds of chert are practically absent. Replacement of the fossils by beekite and other forms of silica is not uncommon at certain horizons, the various species of *Syringopora* and other corals being especially prone to this replacement.

Good examples occur in the *Camarotœchia-proava* Band, and again in the *Cyrtina-carbonaria* Beds of the type-districts, while partial silicification of the coral-surfaces is characteristic of the *Seminula-gregaria* Zone and the Lower *Michelinia* Beds in several districts. In all cases, the interstratification of these silicified layers with beds in which no such replacement occurs appears to point conclusively to the silicification having taken place contemporaneously with the formation, or at all events previous to the solidification of the deposit in which it occurs.

Correlation.

The pre-Carboniferous land-surface in the North-West of England, upon which the rocks of Lower Carboniferous age now rest, does not appear to have been submerged until some time after the Carboniferous sea had invaded the South-Western Province. This is shown by the almost entire absence from the North-Western Province of the lower zones of the Bristol District, namely, all the beds below Z_2 of Dr. Vaughan's classification. The possible exception to this generalization: namely, the deposits found in Pinskey Gill in the Ravenstonedale District, though undoubtedly representing the lowest horizon met with, are difficult to correlate with any beds in the Bristol succession. The beds lie in a pocket in the Lower Palæozoic rocks, and are overlain by the Shap Conglomerate which elsewhere forms the usual base of the Carboniferous deposits in Westmorland.

[1] J. W. Jackson, Geol. Mag. dec. 5, vol. vii (1910) p. 78.

So far as stratigraphical evidence is concerned, the *Spirifer-pinskeyensis* Beds may be of any age between Upper Devonian and the *Zaphrentis* Zone of the Bristol succession inclusive. The evidence from fossils, especially fish-remains, taken together with the general probabilities, though perhaps not absolutely conclusive, appears to point to the deposits being of Carboniferous rather than Devonian age, although the exact correlation of these beds with the corresponding beds in the South-Western Province at present remains unsettled.

With the exception, then, of the depression in which the Pinskey Beds occur, the North-Western Province was not submerged until a period when the upper portion of the *Zaphrentis* Zone was being deposited in the South-Western Province, while the submergence of some parts of the area did not take place until a still later period, when the C_2 beds of Bristol were being laid down. Judging by the character of the deposits first laid down, the Lower Palæozoic floor on which the Carboniferous rocks now rest must have been of the nature of a peneplain rather than a plain of marine denudation.

The earliest deposits, consisting as they do of dolomites and porcellanous limestones almost free from admixture of mechanical sediments, would appear to have been laid down in a land-locked lagoon-like area, from which wave- and current-action was entirely excluded. This supposition is confirmed by the character of the organisms which are entombed in these deposits. The presence of calcareous algæ, in such abundance as occasionally to make up the bulk of the rock, sufficiently testifies to the lagoon-like conditions which prevailed during their growth; while the wealth of brachiopods, such as *Athyris glabristria* and *Camarotœchia proava*, some of which occur unbroken, with their valves united and their brachial supports intact, points to the same conclusion. In the case of *Athyris*, even the delicate external fringes are not infrequently found still attached to the surface of the shell.

The dolomitization of the limestones, if we regard it as practically contemporaneous with the deposits, would seem most naturally to have taken place under conditions similar to those which now exist in the neighbourhood of barrier-reefs and atolls, as shown by the recent investigation on the composition of coral-reefs.[1] An interesting point in connexion with the distribution of these earlier deposits is their relation to the underlying Lower Palæozoic rocks over the North-Western Area. According to one view, the Lower Carboniferous sediments were deposited against an island of Lower Palæozoic rocks which rose above the sea near the centre of the area, so that, as this island sank, it was covered by successively higher deposits of Carboniferous age, and its centre may even have remained above the surface throughout the duration of the Lower Carboniferous sea.

[1] Report of the Coral-Reef Committee of the Royal Society: 'The Atoll of Funafuti' 1904.

Another view, which has been strongly advocated for many years past by Dr. Marr, supposes that the Lower Carboniferous deposits were laid down upon an even surface of Palæozoic rocks over the whole site now occupied by the Lake District, and subsequently elevated into a dome which has been denuded to form the present ring of Carboniferous rocks.

The results of the investigation recorded above would appear to show that the latter view is almost certainly correct. The lowest deposits met with in the North-Western Province occur in close proximity to the present margin of the Lake District, namely, between Pooley Bridge and Shap Wells, at the foot of the Howgill Fells in Ravenstonedale, at Meathop in the Arnside District, and near Elliscales and Marton in the Furness District.

As we travel away eastwards and south-eastwards from the Lake District, we find that the lower Shap dolomites thin out. Hence, far from being an island at that period, the present site of the Lake District probably represents the portion of the area first submerged beneath the Carboniferous sea, while land lay to the east over the tract now occupied by the Cross-Fell range. Further evidence of the same kind is forthcoming from the Ingleborough and Penyghent area to the south-east, in which area submergence does not appear to have taken place until a still later period after the deposition of the *Michelinia* Zone at Arnside.

The present outcrop of Lower Carboniferous rocks, as shown in the index-map published by the Geological Survey, forms an irregular ring round the outskirts of the Lake District, and it is possibly this arrangement which first gave rise to the suggestion that they had been deposited against an island, in much the same manner as the similar beds in Northumberland are regarded as having been deposited against the denuded stump of the old Cheviot volcano. A detailed examination, however, of the dip of the Carboniferous strata which form this ring shows that they constitute the inner edge of a denuded dome, and that, if continued, they would easily clear the highest summits of the Cumbrian Hills.

The beds corresponding to the C Zone of the Bristol District are most probably represented by all except the lowest portion of the *Athyris-glabristria* Zone, together with the whole of the *Michelinia* Zone. The *Seminula* Zone appears to correspond exactly with the *Productus-corrugato-hemisphericus* Zone, while the Lower and a portion of the Upper *Dibunophyllum* Sub-zones correspond very closely in the two areas. A difficulty lies in drawing an exact line in the North-Western Province which will represent the base of the *Cyathaxonia* Beds of the Midland Area; but this may be provisionally drawn somewhere about the Scar Limestone or the beds immediately overlying it, at which horizon *Cyathaxonia cornu* has been found, though sparingly, in the Westmorland Pennines.

The Submergence of the Pennine Area.

In considering the date of this submergence, much interesting evidence is afforded by the Brownber Pebble-Bed, which lies a few feet above the *Thysanophyllum* Band. In the first place, this bed marks an important change which took place in the physiography of the region. Hitherto the Carboniferous beds had been deposited in shallow land-locked seas or lagoons, which favoured the formation of dolomites and fostered the growth of calcareous algæ. The deposits laid down under these conditions were characterized also by the absence of mechanical sediment and freedom from wave- and current-action. During their deposition a land-barrier must have existed to the east of the Shap District in the neighbourhood of the present Pennine range; this is evident from the absence from the Pennine area of any Carboniferous deposits older than the *Thysanophyllum* Band. At the time, however, when this band was being deposited a general submergence took place over the North-Western Province, and for the first time the present site of the Cross-Fell range was covered by the waters of the Carboniferous sea. This is shown, not only by the presence of *Thysanophyllum* at the base of the Carboniferous succession on the south side of Roman Fell, but also by the occurrence of the oolitic Brownber Pebble-Beds over the whole of the Shap and Ravenstonedale Districts and the Roman-Fell area. This submergence of the eastern land-barrier abolished the lagoon-conditions which had hitherto prevailed, letting in the sea from the east with the accompanying effects of wave- and current-action. The distribution of the quartz-pebble beds is of importance in this connexion, for the material of which they are principally composed undoubtedly originated in the Cross-Fell area and travelled westwards. The original source of the pebbles is difficult to determine; but it seems probable that it may be traced to the quartz-veins which occur in the Lower Palæozoic rocks, especially in the Skiddaw Slate Series of the Cross-Fell Inlier, and notably the rocks of this age now exposed in Brownber Pike, which had been plentifully injected with quartz-veins in pre-Carboniferous times.

The effect of wave-action is manifested by the rounding of the quartz-pebbles, while the presence of strong currents setting in from the east is indicated by the sifting of the material and the transport of the pebbles and sand over a large area to the west of Appleby hitherto free from mechanical sediment. The markedly false-bedded character of the pebble-beds and the fragmentary condition of the shells which they contain further bear witness to current-action. The pebbles are, on the whole, largest and most abundant in the east of the area under Roman Fell, and gradually die away when we trace this horizon into the Western Districts. In the intermediate area to the west of Kendal, the deposit is represented under Scout Scar by the calcareous grit which closely resembles the band that occurs at the same horizon at the base of the series in Scordale Beck.

X. Palæontology.

Introduction.

In the preparation of the following accounts of new and little-known forms of corals met with during the examination of the area described in the foregoing pages, I have received the greatest assistance from Mr. R. G. Carruthers, to whom I here offer my most sincere thanks, and after whom I have named the new genus described below. To Dr. Ivor Thomas I am indebted for advice regarding the affinities of the Productids collected. I am also greatly indebted to Dr. A. Smith Woodward, F.R.S., and Miss Madeline Munro for their kindness in allowing me to publish descriptions of the new forms of fish-teeth and bryozoa which appear in Appendix I and Appendix II respectively.

I have also to thank my friend Prof. T. McKenny Hughes, F.R.S., for the special facilities which he has afforded me for studying M'Coy's specimens of Carboniferous corals and brachiopods preserved in the Sedgwick Museum at Cambridge, and for leave to cut sections of the type-specimens of *Caninia subibicina* and *Cyathophyllum multilamellatum*, photographs of which appear in the accompanying plates.

In conclusion, I wish to express my indebtedness to Mr. J. W. Tutcher for the admirable photographs of brachiopods which are reproduced in Pl. LI, and the corals (fig. 1 & fig. 2 *a*), reproduced in Pl. XLIX.

Carruthersella, gen. nov.

Corallum simple, with an outer zone of dissepiments not radiated by the septa. Columella strong, formed of straight lamellæ in complete contact, mostly separated from the major septa, although some may be in direct connexion.

The genus is closely allied to *Aulophyllum* and *Carcinophyllum*, but differs in having a solid columella formed of straight radiating lamellæ in complete contact throughout; it differs from *Lophophyllum* in having a purely dissepimental outer area, not radiated by septa.

Carruthersella compacta, sp. nov. (Pl. XLVIII, figs. 1 *a*–1 *d*.)

External characters.—Corallum simple, elongate-conical.

The largest specimen met with measures 17 mm. across the calyx, but the length of this specimen is unknown: it must have exceeded 35 mm. Cross-section circular. Calyx deep, with a solid columella projecting as a well-defined boss. In well-preserved specimens the proximal end is seen to bifurcate, so as to form two subequal root-like processes. Surface smooth, or covered with inconspicuous longitudinal striæ and well-marked growth-lines.

Transverse section (figs. 1 *a*–1 *c*).—Central area well defined, formed of a solid and conspicuous spindle-shaped columella, composed

of a narrow plate from which radiate fifteen to twenty closely-packed lamellæ, usually in contact throughout this area: the majority of these lamellæ are directly continuous with the attenuated ends of the major septa; occasionally, additional lamellæ appear to be inserted, and occupy positions facing the minor septa, but these do not as a rule reach the central plate, and occur as bifurcations towards the outer margin of the columella.

The central plate appears to be continuous with the counter-septum, and with one of the major septa which bound the fossula. There appears to be a tendency for the lamellæ forming this compact columella to separate slightly in the neighbourhood of the calyx in the adult form.

In sections through the calyx there is also occasionally seen a tendency to the formation of a pseudo-wall dividing off an inner nucleus round the central plate (Pl. XLVIII, fig. 1 *c*).

The medial area is radiated by very strong major septa, which taper rapidly into fine thread-like prolongations continuous with the lamellæ of the columella, the bases of the inner ends of these septa being thickened and fused together to form a pseudo-wall.

The minor septa are practically confined to this thick pseudo-wall; they are visible in thin transparent sections, as short thick spines alternating with the major septa. A small and inconspicuous septal fossula is present, which is marked by the shortened cardinal septum.

The outer area is formed of a narrow zone, of somewhat coarse dissepiments, and is not radiated by the septa. This outer zone is only developed in the neighbourhood of the calyx in mature specimens.

Longitudinal section (fig. 1 *d*).—The central columella is seen to be composed of thickened and somewhat undulating, closely-packed, vertical lamellæ which are irregularly anastomosing; but the figured section (1 *d*) is cut too far from the axis to show these clearly.

The medial area is composed of a broad zone of somewhat loose vesicular tabulæ arranged in oblique rows, the convex surfaces pointing upwards and outwards. The outer area is made up of nearly vertical rows of smaller vesicles, the convex walls of which point upwards and inwards.

All the specimens of this interesting genus so far collected belong to the same species.

Horizon and locality.—Summit of the *Seminula-gregaria* Sub-zone. Meathop Fell, Arnside District.

CARCINOPHYLLUM SIMPLEX, sp. nov. (Pl. XLVIII, figs. 3 *a*–3 *c* & 4 *a*–4 *b*.)

Corallum simple cornute, tapering rather rapidly. Surface covered by well-marked, coarse, vertical ribbing, and by distinct but irregular growth-constrictions. Specimens occur measuring up to 2·5 cm. in length, with a maximum width of 2 cm.

Transverse section.—If a set of serial sections be examined, it is found that in the earliest stages the central area is not composed of vesicular tissue, but is occupied by a columella composed of a number of thick, irregularly twisted, vertical lamellæ, the majority of which are continuous with the inner ends of the major septa. The spaces between these are almost filled with secondary stereoplasm, which is also deposited thickly in the interseptal area. In the later stages (fig. 3 *c*) the majority of the septa are discontinuous with the lamellæ; but the central columella remains attached, even in the most mature stages, to one thickened major septum, which appears in all cases to be the counter-septum. The medial area is radiated by the major septa, which are rather thick and blunt and few in number. In a transverse section having a diameter of 17 mm. there are twenty-eight major septa; these are confluent at their bases to form a thick Zaphrentid type of wall. The minor septa are inconspicuous in the earliest stages, and when they first appear are entirely buried in the deposit of stereoplasm. In adult forms they are never more than a quarter of the length of the major septa. It is only in calicinal sections of big specimens that dissepiments appear, when they form large loose vesicles of the *Carcinophyllum* type.

Longitudinal section.—The central area is composed of the sections of the irregular twisted lamellæ which form the columella; these are connected by loose vesicular tabulæ, which pass outwards to the epitheca in a highly irregular manner.

This interesting species appears to be essentially a *Carcinophyllum*, although it is not until the final growth-stages that the non-septate dissepiments of that genus appear; the curious contorted columella is of a much simpler type than in any species hitherto described.[1]

Horizon and localities.—*Seminula-gregaria* Sub-zone, *Spirifer-furcatus* Band and underlying bed, Meathop, Arnside District; and at the same horizon at Marton, Furness District.

Lophophyllum meathopense, sp. nov. (Pl. XLVIII, figs. 2 *a*–2 *e*.)

This species conforms exactly to the revised diagnosis of the genus *Lophophyllum*, as recently defined by Mr. Carruthers.[2]

Corallum.—Elongate-cylindrical, usually twisted, tapering rather sharply at the curved proximal end. Epitheca thin; external surface covered with fine growth-lines and occasional deeper constrictions. Specimens occur, measuring up to 25 cm. in length and 3·25 cm. in diameter. Calyx deep: a specimen which has the above-mentioned diameter at the base of the calyx has a depth of calyx of 4·5 cm.

Transverse section.—In the earlier stages (Pl. XLVIII, fig. 2 *c*) the major septa only are developed, and there is no peri-

[1] [When this paper was read, this form was described as a new genus—*Meathopia*. Investigation of further material appears to render this separation unwarranted, as pointed out to me by Mr. R. G. Carruthers.—*E. J. G., November 1912.*]

[2] Trans. Roy. Soc. Edin. vol. xlvii (1909) p. 152.

pheral zone of dissepiments. The septa are somewhat flexuous and thick, tapering towards their inner ends, which either reach to the centre, or else coalesce with adjoining septa forming groups of which one septum is continued to the centre. In more mature stages a septal fossula is present and the central plate becomes more irregular, but can be seen to be continuous with the attenuated inner end of the counter-septum (Pl. XLVIII, figs. 2 *a* & 2 *d*).

A zone of dissepiments is developed, which becomes wider as the diameter of the calyx increases; this zone is radiated by fine major and minor septa, the latter being continued into the medial area as short thickened spines; in a section having a diameter of 32 mm. there are fifty stout major septa in the medial area, which become rapidly attenuated where they enter the central area, and also decrease in thickness in the peripheral zone.

A longitudinal section shows a vertical undulating median plate. The tabulæ are rather widely spaced and arch steeply where they intersect the median plate (Pl. XLVIII, fig. 2 *e*).

The dissepimental zone is finely vesicular and of moderate width, and the vesicles are arranged in vertical rows.

This form resembles in general characters *Lophophyllum cherneyense* Carruthers.[1] It differs from that species in having a much more elongated form, in possessing a greater number of septa which are thickened in the medial area, and in having strong minor septa.

Horizon and localities.—*Seminula-gregaria* Sub-zone. Meathop-Marsh Quarry, Arnside District; Marton, Furness District.

LOPHOPHYLLUM FRAGILE, sp. nov. (Pl. XLIX, figs. 5 *a* & 5 *b*.)

Corallum cornute; epitheca smooth, with occasional growth-constrictions.

Transverse section.—Septa straight, numerous and delicate, not thickened, not reaching the centre, but continued outwards to the theca; inner wall inconspicuous. Central area with a short, thin columellar plate, the major septa projecting only a short distance into this area. Concentric intersections of the tabulæ few in number: appearing as broad bands, on account of the flat and generally horizontal disposition of the tabulæ. External area very broad, radiated by both the major and the minor septa; dissepiments numerous and fine; cardinal fossula poorly developed, only indicated by the slightly-shortened cardinal septum which stops short of the central area.

Longitudinal section.—Dissepimental area broad, nearly as wide as the central area; tabulæ thin and rather widely spaced, frequently showing a marked tendency to a horizontal arrangement, but curving sharply upwards near their intersection by the columellar plate.

This species is distinguished by its slightly-developed columellar plate, the delicate structure of the septa and dissepiments, the short

[1] Trans. Roy. Soc. Edin. vol. xlvii (1909) pl. i, figs. 1 & 2.

and unthickened character of the major septa, and the relatively great width of the dissepimental zone.

Horizon and locality.—The upper portion of the *Michelinia* Zone. Arnside.

Lophophyllum vesiculosum, sp. nov. (Pl. XLVIII, figs. 5 *a* & 5 *b*.)

In transverse sections this species is characterized by a distinct and thickened plate and the regular symmetry of the central area. The radial lamellæ are few in number, and are composed of the attenuated inner ends of some of the major septa. The concentric intersections are numerous, indicating the closely-set and strongly-arched character of the tabulæ; these intersections diminish towards the outer part of the median area, where the tabulæ flatten out, while at the extreme outer margin next to the dissepimental area, stereoplasmic thickening of the tissues takes place (Pl. XLVIII, fig. 5 *a*).

The external area is broad: it consists of a wide zone of fine closely-set dissepiments, which are radiated by major and minor septa, and a narrow border of rather coarse vesicles not radiated by the septa. The longitudinal section (fig. 5 *b*) shows these characters clearly.

This species differs from *L. meathopense* by the thickened central plate; by the more numerous, closely-set tabulæ in both the central and the medial zones; by the broad outer zone of dense dissepimental tissue; and by the outer border of coarse tissue not radiated by the septa.

Horizon and locality.—*Seminula-gregaria* Sub-zone. Meathop, Arnside District.

Lophophyllum ashfellense, sp. nov. (Pl. L, figs. 9 *a* & 9 *b*.)

Corallum simple, markedly cornute, tapering rapidly. Surface with fine longitudinal ribs and marked concentric growth-constrictions. Calyx deep; central plate projecting slightly above the floor of the calyx, forming a narrow ridge. A distinct septal fossula is present in the cup, which is marked by a shortened septum and also by the slightly Zaphrentid-like curving of the septa bounding the fossula, which coalesce at their inner margins with contiguous septa. The proximal end bifurcates to form broad root-like processes, which in all specimens collected have grown round the shell of a brachiopod, a bryozoan, or a coral. The largest specimen met with measures over 11 cm. in length, and its diameter across the cup is 4·5 centimetres.

Transverse section (fig. 9 *a*).—The columella is very thin and lath-like. In the final growth-stages it may appear isolated in the centre of the tabulate area, but lower down it is usually in direct connexion with both cardinal and counter major septa, giving a general bilateral symmetry to cross-sections; it is surrounded by irregular wavy lines, due to the truncation of the surrounding tabulæ.

There are fifty-two major septa in a specimen having a diameter of 23 mm. The majority of these stop short some distance from the centre. They are not much thickened except at their bases, where they enter the vesicular zone. The minor septa are short, and confined to the vesicular area; some of them do not even reach the inner margin of that area. In the peripheral zone the dissepimental tissue is abundant and closely set.

Longitudinal section (fig. 9 *b*).—The central plate appears as a thin rod intersecting the tabulæ, which are slightly arched and moderately closely set. The zone of dissepiments consists of vertical rows of very fine vesicles. The columellar line is not usually continuous, but the interruptions are due to local curvature of the corallum taking the columella out of the line of section.

Horizon and locality. — *Productus-corrugato-hemisphericus* Zone, Gastropod Beds. Ashfell Sandstone, Ashfell Edge, Ravenstonedale District.

Clisiophyllum multiseptatum, sp. nov. (Pl. L, figs. 1–4 *b*.)

This species resembles closely *Cl. keyserlingi* M'Coy,[1] but differs from that species in having (1) more closely-set septa (having sixty when the type of the same diameter has fifty); (2) more closely-set tabulæ in the centre; (3) a central area more sharply separated from the median area. In *Cl. multiseptatum* the central plate becomes more prominent with age, while in *Cl. keyserlingi* it becomes less so. The coral frequently attains a length of 5 inches, and shows a spiral mode of growth. The epitheca, though on the whole smooth, shows annular wrinkles and, in unrolled specimens, distinct longitudinal ribbing. The cross-section is typically circular, becoming elliptical in the neighbourhood of the calyx in well-grown specimens. The septal fossula is well developed in the adult stage.

Horizon.—The summit of the *Michelinia* Zone, where it constitutes an important stratigraphical band, which forms a passage-bed between the *Michelinia* Zone and the Gastropod Beds. A similar coral, indistinguishable from the type-specimen, occurs in the Trowbarrow Shale-Bed at a much higher horizon, about the base of the Upper *Dibunophyllum* Sub-zone.

Localities.—Blackstone Point and Storth Road, Arnside District. Also at the same horizon in the Ravenstonedale, Kendal, Grange, and Furness Districts.

[Quite recently Dr. Vaughan[2] has figured a similar coral from the same horizon under Ingleborough, under the name of *Clisiophyllum ingletonense*. This species differs, however, from the form described above in having septa always strongly thickened in the median area, and its inner septa rarely projecting into the median area.]

[1] 'British Palæozoic Rocks & Fossils' 1855, pl. iii *c*, fig. 4.
[2] Proc. Yorks. Geol. Soc. n. s. vol. xvii, pt. iii (1911) p. 251.

Campophyllum ciliatum, sp. nov. (Pl. XLVIII, figs. 6 *a*–6 *c*.)

Corallum rather small, simple, cylindrical. Epitheca with coarse longitudinal ribbing and very well-marked growth-lines. Hollow root-like processes are given off from the proximal end.

Transverse section.—Central area tabulate and wide. Outer margin of the area radiated by a series of thickened pointed septa, which are undulating and contiguous near their bases. They usually occur in pairs, and have a tendency to coalesce near their inner ends, one of them being prolonged as a single thread-like septum. The fused bases of these septa give the appearance of an inner wall; outside this 'wall' occurs a zone of fine tissue radiated by the septa. There is an external zone of very coarse vesicular tissue not radiated by the septa. A septal fossula is but feebly developed.

Longitudinal section.—Tabulæ widely spaced, and interrupted by occasional circular vesicles, which appear like nearly spherical bubbles in a longitudinal section.

Remarks.—This form is doubtfully placed under the genus *Campophyllum*. In many respects it appears to resemble Billings's genus *Blothrophyllum* from the Devonian (Corniferous Limestone) of Ontario, as figured in the 'Canadian Journal'[1] and refigured by Mr. L. M. Lambe in 'Contributions to Canadian Palæontology'[2]; this genus is characterized by the very large and blister-like vesicles which form the outer zone, but has a distinct septal fossula and minor septa.

Horizon and locality.—*Seminula*-*gregaria* Sub-zone. Meathop, Arnside District.

Caninia subibicina M'Coy. (Pl. XLIX, fig. 3.)

The type-specimen of this species figured by M'Coy,[3] is preserved in the Sedgwick Museum, Cambridge. It was obtained from the Kendal District of the North-Western Province. A figure of a transverse section cut from this type-specimen is given here, through the courtesy of Prof. McKenny Hughes. There can be little doubt that the horizon from which the specimen was obtained is that of the *Michelinia* Zone of the classification adopted in the present paper. The coral is not infrequently met with in the upper portion of this zone at Arnside, and in other exposures at the same horizon in the Kendal, Grange, and Furness Districts.

In the Shap District it enters somewhat earlier, and is there characteristic of the *Thysanophyllum* Band.

Zaphrentis koninckı, forma kentensis nov. (Pl. XLIX, fig. 4.)

This form differs from the typical form of this species described by Mr. Carruthers,[4] in its greater size and in the more pronounced

[1] Canadian Journal (Canad. Inst.) n. s. vol. iv (1859) fig. 25 & p. 130.
[2] Geol. Surv. Canada, vol. iv, pt. ii (1901) p. 171 & pl. xv, fig. 1.
[3] 'British Palæozoic Rocks & Fossils' 1855, pl. iii *i*, figs. 35 & 35*a*.
[4] Geol. Mag. dec. 5, vol. v (1908) p. 67.

development of the minor septa. Specimens having a length of 9·5 cm. and a diameter of 3·5 cm. across the calyx are not uncommon. This form has been stated by Dr. Vaughan to bear a striking resemblance to *Cyathophyllum* ϕ Vaughan.[1] A transverse section of a typical specimen from Gascow is here figured.

Horizon and localities.—Abundant in the upper portion of the *Michelinia* Zone in the North-Western Province; Arnside and Storth-Road section in the Arnside District; Gascow and Plumpton in the Furness District; Park Head and Frith Hall in the Grange District.

CYATHOPHYLLUM MULTILAMELLATUM (M'Coy).[2] (Pl. L, figs. 5–7.)

The type-specimen of this species was obtained by M'Coy from Arnside. The species occurs abundantly in the upper portion of the *Michelinia* Zone—not only at Arnside, but wherever that horizon is exposed. It is not found above that zone; but a closely allied (though somewhat smaller) form is met with in the lower portion of the zone, at Brigsteer in the Kendal District and elsewhere. M'Coy's name is retained here, as the exact relation of this form to *C. murchisoni* (Ed. & H.) remains uncertain until the type of that species is found and cut. There is, however, a certain variation of the form in the different specimens collected from this horizon. These may be divided into two groups:—Group A differs both from *C. murchisoni* and *C.* ϕ in having more widely-spaced septa and a more strongly-marked fossula, while the tabulæ are intermediate in type between these two forms (figs. 6 & 7). This form appears to be identical with M'Coy's *C. multilamellatum*, a transverse section of which, cut from the type-specimen preserved in the Sedgwick Museum, I am able to give for comparison through the courtesy of Prof. McKenny Hughes (fig. 5). Group B contains forms having still more widely-spaced septa and an even more distinct cardinal fossula.

THYSANOPHYLLUM PSEUDOVERMICULARE (M'Coy). (Pl. XLIX, figs. 2 *a*–2 *d*.)

This species was originally described by M'Coy under the name of *Cyathophyllum pseudovermiculare*, from specimens collected in the Kendal District.[3]

It is refigured here, in order to show (1) the great variation in the size of the corallites and the characteristic lateral budding (fig. 2 *a*); (2) the coarsely-ribbed epitheca (fig. 2 *a*); (3) the outer zone of coarse vesicular tissue, which is typically not radiated by the septa, except in young forms (fig. 2 *b*); and (4) the marked tendency for one of the septa to be prolonged into the centre of the tabulate area, as shown in figs. 2 *b* & 2 *c*.

This species would appear to belong to Nicholson & Thomson's

[1] Geol. Mag. dec. 5, vol. v (1908) p. 70.
[2] 'British Palæozoic Rocks & Fossils' 1855, pl. iii *c*, figs. 3 & 3 *a*.
[3] *Ibid.* p. 86 & pl. iii *c*, fig. 8.

genus *Thysanophyllum*,[1] and subsequently figured by Thomson.[2] It agrees with the latter author's figure of *Th. minus* in most particulars, especially in the fact that one septum is characteristically prolonged into the centre of the tabulate area, and that a few of the septa occasionally extend into the outer vesicular zone. M'Coy's species seems to differ from both of Thomson's species, chiefly by the coarser character of the vesicles in the peripheral zone. This species appears to represent an early form of *Lonsdalia floriformis*. Mr. R. G. Carruthers, who has devoted special attention to the ancestry of *Lonsdalia*, has demonstrated that *L. floriformis* passes through a very distinct *Thysanophyllum* stage in early life: this would appear to show that *Lonsdalia* has descended, not through *Dibunophyllum*, as sometimes suggested, but through *Thysanophyllum*. This view seems to be further strengthened by the existence of the form intermediate between *Lonsdalia* and *Thysanophyllum*, already mentioned as occurring with *Stenophragma* in Ravenstonedale.

Horizon and localities.—This species is limited to an horizon near the summit of the *Athyris-glabristria* Zone, in the Eastern Districts of the North-Western Province. It is found at many places between the River Eamont and the Dent Fault, in the type-districts; in Hall-Head Quarries and in the cuttings for the Underbarrow and Brigsteer roads, Kendal District; above Broad Oak in the Grange District; and in Dobby-Hole Sike to the south of Roman Fell.

Diphyphyllum aff. lateseptatum M'Coy. (Pl. L, figs. 8 *a* & 8 *b*.)

This form differs from *D. lateseptatum* of M'Coy in the greater breadth of the tabulate area, which extends across four-fifths of the width of the corallite. The tabulæ are perfectly horizontal throughout the greater portion of their extent, but bend down steeply at their margins, and frequently have the appearance of bifurcating before reaching the peripheral zone, which consists of a double row of very fine vesicles (Pl. L, fig. 8 *b*).

In transverse sections the oblique lateral margins of the tabulæ are intersected, to form sparse interseptal tissue (fig. 8 *a*).

Horizon and localities.—Base of the *Productus-corrugato-hemisphericus* Zone. Blackstone Point, Arnside District; Tarn Sike, Ravenstonedale District.

Lithostrotion (Nematophyllum) minus M'Coy.

The form figured by M'Coy in 1849 in the Annals of Natural History (ser. ii, vol. iii, p. 17), and afterwards in his 'Palæozoic Rocks & Fossils' 1855, p. 99 & pl. iii *b*, fig. 3, was collected from the Kendal District, where it occurs abundantly on the summit of Scout Scar and Kendal Fell. M'Coy gives good figures, and the type-specimens are preserved in the Sedgwick Museum at Cam-

[1] Proc. Roy. Soc Edin. vol. ix (1876) p. 150.
[2] Proc. Phil. Soc. Glasgow, vol. xii (1880) pp. 255–58 & pl. iii, figs. 11–12, 14.

bridge, so that there can be no mistake as to the form which is characteristic of the Upper *Productus-corrugato-hemisphericus* Zone in the North-Western Province. It is for this reason that M'Coy's name has been adopted for this zonal form in the stratigraphical portion of this paper. At the same time, there is good reason to suppose that this species is synonymous with *Lithostrotion basaltiforme* of several authors. Llwydd's original type of *Lithostrotion* is a basaltiform species, as shown by his figure, and not a dendroid form; but, unfortunately, we do not know the horizon in Wales from which it was obtained.[1]

Phillips's type of *Cyathophyllum basaltiforme*[2] came from Moughton Scar in Ribblesdale, where *N. minus* occurs abundantly at the same horizon as in the Kendal District; but, as the figures and description are very inferior to M'Coy's, it has been considered better to emphasize the latter for stratigraphical identification.

Conybeare & Phillips's name *L. basaltiforme* (1822) has been widely adopted for all large basaltiform corals of that genus from the Carboniferous rocks; indeed M'Coy's type-specimens in the Sedgwick Museum are so labelled, and appear under this title in Mr. Woods's Catalogue of the type-fossils in the Sedgwick Museum.

Some confusion may arise from M'Coy's statement that the corallites are inseparably united, and cannot be divided. This statement is not true of the Kendal specimens, and the separation or non-separation of the corallites appears to be entirely a question of mode of preservation and weathering. The separation of the corallites is most difficult to effect in specimens which have been entirely recrystallized.

Vaughania,[3] gen. nov. (Pl. XLVIII, fig. 7 & text-figs. 4–6, p. 565.)

Corallum discoid, upper surface convex, margin lobulate; size variable, specimens occur measuring up to 5 cms. in diameter. Thickness in centre=3 or 4 mm., becoming somewhat less towards the margin. Base concave, covered with a well-marked wrinkled epitheca, wrinkles arranged in festoon-like concentric folds parallel to the margin. Corallum apparently free. Corallites very short, closely set, polygonal, as a rule irregularly hexagonal; on an average, ten corallites occur in a length of 4·5 cm. Calices shallow, rather over 1 mm. deep, walls less than 0·75 mm. thick; floors nearly smooth and flat, but curving upwards at the margins to meet the base of the walls.

In well-preserved specimens the surface of the walls presents a somewhat rugose appearance, resembling Nicholson's figure of *Cleistopora geometrica*,[4] but there are no definite ridges or striæ representing septa.

[1] 'Lithophyllacii Britannici Ichnographia' epistola 5, tab. xxiii (1760).

[2] 'Geol. of Yorks.' pt. ii (1836) p. 202 & pl. ii, fig. 21.

[3] I have named this new genus in honour of Dr. Arthur Vaughan, and in testimony of my admiration for his epoch-making work among the Lower Carboniferous rocks and fossils.

[4] Geol. Mag. dec. 3, vol. v (1888) p. 151.

The corallum is traversed by a system of large perforations or tubes, arranged on a definite plan. This is found in all well-preserved specimens, though it is liable to slight variation in detail.

Round the base of the wall of each calyx runs a polygonal or roughly circular perforation or ring-canal, which follows the contour of the wall; this lies just inside the angle formed by the junction of the wall with the floor of the calyx, and slightly below the level of the floor. Thus the base of each wall is traversed by two such tubes bordering the margins of two contiguous corallites (fig. 4, below). From these ring-canals branches are given off, which open by pores into the floor of the calices near the base of the walls (fig. 5). Other branches are given off in the opposite direction from the ring-canals and traverse the wall horizontally, connecting the ring-canals of two adjacent corallites (fig. 6). Other pores are also occasionally seen, opening higher up on the walls of the calices; these are, however, more irregular in their distribution.

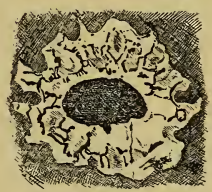
Figs. 4–6.—*Vaughania cleistoporoides*, gen. et sp. nov.

5 [Natural size.]

4

[× 22 diameters.]

6 [Natural size.]



The pores opening round the basal margin of the calices are fairly numerous, and are placed close together, the distance between them being generally not much greater than the diameter of the pores themselves (fig. 5).

In microscopic sections the walls and floors of the corallites exhibit a finely-crystalline fibrous structure, similar to that which characterizes many recent corals. The long axes of the fibres are arranged perpendicularly to the walls and floors of the calices (fig. 4, above). There is no trace of the trabecular structure figured by Nicholson in his descriptions of *Cleistopora* and *Palæacis*, while tabulæ are entirely wanting. This compact fibrous cœnenchyma is perforated by the tubes described above; and, in the neighbourhood of the tubes, the fibres are arranged in a radial manner perpen-

dicularly to the walls of the tubes (fig. 4). Vertical sections cut at right-angles to a corallite-wall show two perforations below the base of the wall and on each side of it, representing transverse sections of the two ring-canals of contiguous corallites (fig. 4, p. 565). From these, in many sections, tubes can be observed passing obliquely outwards and upwards, and penetrating the floors of the calices at the base of the walls, where they terminate at the surface to form the pores already described. In horizontal sections, prepared so as to expose the base of the walls a short distance below the floors of the calices, the system of ring-canals and their connecting tubes can be well seen, the canals being rendered conspicuous by their infilling of darker argillaceous material (fig. 6).

Affinities and differences. — In general appearance in hand-specimens this organism, especially when weathered, closely resembles the form from the Avon section referred by Dr. Vaughan to *Cleistopora (Michelinia) geometrica* Ed. & H.[1] It differs, however, from this genus, as described and figured by Nicholson (*op. supra cit.*), in the following points: —

1. The absence of the trabecular structure which characterizes that genus.
2. The presence of compact fibrous cœnenchyma, forming the whole of the corallum.
3. The presence of a definite system of ring-canals and branches.
4. The presence of a well-developed basal epitheca, which is unattached.

From *Pleurodictyum* the form here described differs by the calices being low and vertical, not funnel-shaped; by having no trace of tabulæ or septal spines; by not being attached; and by the absence of the commensal vermiform body. Again, the ring-canals which are so characteristic of *Vaughania* have never been observed in *Pleurodictyum*. The former resembles *Pleurodictyum* in the presence of intra-mural pores and of a concentrically striated basal epitheca. It differs from *Palæacis*[2] in

1. Having a much greater number of calices.
2. The corallites not being wedge-shaped, but arranged with their walls perpendicular to the basal plate.
3. The calices having narrow and polygonal walls rising from the basal plate, and not excavated as circular pits in the general mass of the corallum.
4. The absence of vertical striæ in the calices.
5. The regular arrangement of the perforations to form ring-canals.
6. Not being attached.

It resembles *Palæacis* in having rows of pores connecting the corallites, but the minute structure of the basal plate of *Palæacis* is unknown.

It resembles more closely in its internal structure *Microcyathus*,[3] which is formed of fibrous calcareous tissue, and in the possession of a wrinkled basal epitheca; also in the possession of a porous cœnenchyma, which characterizes the base and spaces between the

[1] Proc. Bristol Nat. Soc. n. s. vol. x (1903) p. 99.
[2] J. Haime, in H. Milne Edwards, 'Hist. Nat. Corall.' vol. iii (1860) p. 171.
[3] G. J. Hinde, Q. J. G. S. vol. lii (1896) p. 447.

calices: but the pores in the cœnenchyma of *Microcyathus* are irregular, and can scarcely be described as a definite tubular system.

Our form differs again in general appearance by the polygonal character of the calices, which are closely packed; whereas the cups of *Microcyathus* are some distance apart, and circular in outline: also in the absence of a rugose surface and of blunt spines in the calices, which in *Microcyathus* seem to represent septa.

Vaughania cleistoporoides, sp. nov.

This is the only species of the genus so far known.

Horizon and locality.—Near the base of the *Solenopora* Sub-zone. Stone Gill and Artlegarth, Ravenstonedale District; Shap-Abbey Cliff, Shap District.

Brachiopods.

Camarotœchia proava (Phill.). (Pl. LI, figs. 1*a*–1*c*.)

This species was first figured by Phillips in his 'Geology of Yorkshire' pt. 2 (1836) pl. xii, fig. 37 & p. 223, and described under the name *Terebratula proava* as follows:—'Beak produced; radiations obtuse; mesial fold square.'

Davidson, 'Brit. Foss. Brach.' Monogr. Pal. Soc. vol. ii (1858–63) p. 111 & pl. xxv, fig. 10, refigures Phillips's specimen, and adds the following description:—

'Of an elongated oval shape, with nineteen or twenty small ribs in each valve, but which become obsolete at the beaks; the mesial fold is of but small elevation above the general convexity of the valve, and is ornamented by five ribs; the sinus is shallow.'

He doubts, however, whether it is a good species, and suggests that it may be an abnormal shape of *Camarophoria crumena*.

The type-specimen is preserved in the British Museum.

Our species resembles very closely figures of *Camarotœchia congregata* of Hall, from the Hamilton Group of North America.[1] The size of the specimen, the slight mesial fold and sinus, and the character of the ribbing all agree. Owing to silicification, it is difficult to find well-preserved specimens exhibiting the interior; but one or two collected from the Ravenstonedale District show distinctly an incipient spondylium in the brachial valve. This spondylium and the position and shape of the dental sockets correspond almost exactly with the internal view of *C. congregata* shown in the figures of Hall & Clarke.

Horizon.—This species forms a very marked band in the upper portion of the *Solenopora* Sub-zone, and, when present, occurs in great abundance, making up layers of the rock; it is of great value as a zonal horizon, especially in the type-districts.

[1] J. Hall & J. M. Clarke, 'Palæontology of New York' vol. viii, pt. ii: 'An Introduction to the Study of the Brachiopoda' pt. ii (1894) pl. xliii, figs. 1 & 2–4 (13th Ann. Rep. State Geol. N.Y. for 1893, vol. ii).

Localities.—Piper-Hole Quarry, Ravenstonedale; above Shap-Abbey Cliff, Shap District; under Hall-Head Farm, Kendal District; Low Meathop, Arnside District.

RHYNCHONELLA (PUGNAX) FAWCETTENSIS, sp. nov. (Pl. LI, figs. 2 *a* & 2 *b*.)

Description.—General form subrhomboidal. Shell rather small: an average specimen measures in length 10·5 mm., in width 12 mm., and in thickness 8 mm. Apical angle = about 125°. Plications extend from the beak to the anterior margin. There are six plications on each side of the median fold in the brachial valve. Sinus shallow, only well marked in the anterior portion of the shell. The plaits in the fold are typically three in number, and are usually produced slightly beyond the general margin (fig. 2 *a*).

This small rhynchonellid, although belonging to the same group as *Pugnax pleurodon*, possesses marked and constant characters which differentiate it from that well-known species. The points of difference are:—

1. Mature specimens have a considerably smaller size than *P. pleurodon*.
2. It has a relatively narrow and more swollen form.
3. The sinus is more rounded and less pronounced.
4. There are a smaller number of plications in the sinus.

This form resembles in many respects *Rh. acutirugata* of L. G. de Koninck.[1] It differs from that species, chiefly in the general form of the fold and sinus, and in the character of the apical angle.

Horizon and localities.—*Productus-globosus* Band; *Seminula-gregaria* Sub-zone. Fawcett Mill, Shap District; near Park House, Ravenstonedale District; under Cunswick Scar, Kendal District.

PRODUCTUS GLOBOSUS, sp. nov. (Pl. LI, figs. 4 *a* & 4 *b*.)

Shell small: an average specimen measures 8 or 9 mm. along the hinge-line. Length of specimen, as usually preserved, from umbo to anterior margin = 33 mm.

Pedicle-valve.—General form globular, tapering rapidly to the umbo. Umbonal region greatly inflated, strongly arched and incurved. Hinge-line straight, and scarcely as wide as the greatest width of the shell. Shell devoid of any trace of sinus, but almost uniformly convex.

Ribs very fine, thirty-five in 10 mm., measured at the middle of the anterior portion of the visceral disc. In this region the ribs are but slightly undulating, and the region is typically devoid of intercalated ribs. In the umbonal region, just where contraction takes place rapidly, there is a regular zone of fresh intercalations, as shown in Pl. LI, fig. 4 *a*. Ears covered with numerous well-marked wrinkles, which are confined to these regions. There are no traces of concentric lines of growth over the visceral disc. Groups

[1] 'Faune du Calcaire Carbonifère de la Belgique' pt. vi, Ann. Mus. Roy. Hist. Nat. Belg. vol. xiv (1887) pl. xvi, figs. 1–14.

of short, blunt, and curved spines cluster on the ears, and are continued as a double row along the hinge-line. Spines are also given off sparingly from the skirt, which is slightly undulating.

Horizon and localities.—This form appears to be confined to a definite band at the base of the *Seminula-gregaria* Sub-zone. Friar's Bottom, Ravenstonedale District; Fawcett Mill, Shap District.

Productus aff. globosus.

This form resembles *Pr. globosus* closely, in size and in general appearance. It differs, however: (1) by the more clearly-defined character of the ribs, which are both coarser and more clearly cut; (2) by the more pointed and less globose character of the visceral disc, from which results the fact that the intercalation of fresh ribs takes place much farther from the umbo, in the region near the anterior portion of the visceral disc.

Only two specimens of this form have been met with, at the base of the Lower *Dibunophyllum* Sub-zone, in the Bryozoa Band, east of Roman Fell, in the Pennine District.

Productus rotundus, sp. nov. (Pl. LI, figs. 3 *a* & 3 *b*.)

Pedicle-valve.—Resembles *Productus globosus* in general appearance, but differs in the following points:—

1. Shell slightly larger.
2. The greater width of the shell across the region near the anterior end of the visceral disc, in which region, as also over the skirt, there is in some specimens a slight tendency to a sinus.
3. The coarse character of the ribbing. Seventeen ribs in 10 mm.
4. The continuation of the wrinkles over the visceral disc, producing a slightly scrobiculate appearance in that region.
5. The presence of fine concentric lines of growth, which are specially conspicuous on the skirt.

Horizon and localities.—Abundant in the *Productus-globosus* Band at the base of the *Seminula-gregaria* Sub-zone. Friar's Bottom, Ravenstonedale District; Fawcett Mill, Shap District.

Productus cf. giganteus Mart.

This form is very close to, if not identical with, that figured by Davidson.[1] It differs from the typical *Pr. giganteus* of Martin by its smaller size, more globose form, and slight development of ears. The coarse ribbing characteristic of the type-species is but faintly developed, and the convex valve has the shell greatly thickened in the neighbourhood of the hinge-line. The shell resembles rather closely in external appearance well-grown examples of *Daviesiella llangollensis*; but internal casts of the convex valve show conspicuous eminences, representing the cavities for the fleshy arms shown in Davidson's figure. These casts, indeed,

[1] 'Brit. Foss. Brachiop.' Monogr. Pal. Soc. vol. ii (1858–63) pl. xxxvii.

resemble at first sight those of *Productus sublævis*, originally figured by Sowerby as *Pr. humerosus*.

Horizon and localities.—This form is confined to one horizon in the North-Western Province, at the summit of the *Lonsdalia* Beds, where it is present in such abundance as to make up a definite band at the summit of the Mauld's-Meaburn Limestone. Bank Moor, Gathorn Plain, Shap District; High-Cup Gill, Pennine District.

PRODUCTUS cf. MAXIMUS M'Coy.[1] (Pl. LI, fig. 8.)

This species resembles *Pr. giganteus* in general form, but differs by its much smaller size, the full-grown specimens having a length of about 10 cm. along the hinge-line. It differs also by the more even character of the striæ, and the absence of the large ribs which are so characteristic of Martin's species. From *Pr. corrugato-hemisphericus* Vaughan it differs by its transverse form and its elongated hinge-line. In the specimen figured there are also closely-set spine-bases along the hinge-line.

Horizon.—Characteristic of the Lower *Dibunophyllum* Sub-zone in the North-Western Province. The specimen figured is from this horizon in the Pennine District.

SPIRIFER PINSKEYENSIS, sp. nov. (Pl. LII, figs. 1 *a* & 1 *b*.)

Hinge-line straight, by far the greatest width of the shell. Beak small and depressed. Valves almost equally convex.

Pedicle-valve.—Sinus shallow, with flattened floor and three or four ribs; these may be faint and indistinguishable in the casts, but are distinctly larger than those on the rest of the shell. Surface ornamented with fine concentric lines and occasional indications of radial striæ on the ribs in the sinus. The ribs bounding the sinus frequently bifurcate at some distance from the beak, and are inclined to be raised above the general surface of the shell.

Brachial valve.—Mesial fold flat, scarcely elevated above the general surface of the shell, indistinct, usually divided near the beak to form two ribs which diverge considerably towards the anterior margin, each bifurcating once. The lateral ribs bordering the fold are frequently seen to bifurcate. The anterior margin of the fold is covered with conspicuous concentric growth-lines.

Remarks.—This species bears considerable resemblance to *Sp.* aff. *clathratus* (M'Coy) Vaughan.[2] It differs from Dr. Vaughan's figure of a typical specimen, given in vol. lxi (1905) of this Journal,[3] by its rather less transverse form; by the shallow and flattened nature of the sinus; and by the less numerous and coarser character of the ribs in the sinus.

Horizon and locality.—Pinskey Beds, underlying the Shap Conglomerate. Pinskey Gill, Ravenstonedale District.

[1] T. Davidson, 'Brit. Foss. Brachiop.' Monogr. Pal. Soc. vol. ii (1858–63) pl. xxxix, fig. 4.

[2] Proc. Bristol Nat. Soc. n. s. vol. x (1903) pp. 125–26 & pl. ii, fig. 3.

[3] P. 300 & pl. xxvi, fig. 5.

Spirifer furcatus M'Coy.[1]

This small *Spirifer*, which occurs abundantly near the summit of the *Athyris-glabristria* Zone on Meathop Fell, in Docker Beck, and elsewhere, bears a very close resemblance to M'Coy's figure. It is a somewhat variable form, and does not always show the bifurcation of the ribs clearly at the anterior portion of the shell. In some specimens, apparently belonging to this species, the ribs are more numerous and the bifurcation takes place nearer the posterior margin.

This form approximates occasionally to *Sp. duplicicostatus*, under which name Davidson includes M'Coy's species; but, on the whole, it differs from the typical examples of that species in the following points:—

1. The subquadrate form of the shell.
2. The less numerous and coarser ribs. In the pedicle-valve there is a somewhat marked bifurcation about the third rib from the sinus.
3. The narrower character of the mesial fold, especially towards the anterior border, giving a more parallel and less divergent appearance to the ribbing.
4. The well-marked growth-lines towards the anterior margin of the shell: these are clearly shown in M'Coy's figure.

Horizon and localities.—Very characteristic of the band near the summit of the *Athyris-glabristria* Zone. It is doubtful whether it occurs outside this band in the North-Western Province. A few specimens met with at a slightly lower horizon in the Ravenstonedale District should perhaps be assigned to this form. Meathop Fell, Arnside District; Beck Head, Grange District; Elliscales, Furness District.

Seminula gregaria (M'Coy). (Pl. LI, fig. 5.)

The typical form of the Athyrid selected for the zonal index of the upper portion of the *Athyris-glabristria* Zone in the Shap and Ravenstonedale Districts is shown in Pl. LI, fig. 5. It appears to be identical with M'Coy's '*Atrypa gregaria*,' figured in his 'Carboniferous Limestone Fossils of Ireland' pl. xxii, fig. 18. With regard to its true generic affinities, very little information can be obtained from the occurrences of this species in the North-Western Province, as the specimens are there invariably dolomitized. Dr. Vaughan informs me that the species is probably a *Cryptonella*, but it cannot be definitely assigned to its proper genus, until better specimens, showing internal characters, are obtainable.

Seminula aff. ficoidea Vaughan. (Pl. LI, fig. 6.)

This form bears a close general resemblance to Dr. Vaughan's figure of *S. ficoidea*.[2] It appears, however, to differ from that species by its more swollen character; by its greater length of

[1] See F. M'Coy, 'Syn. Carb. Limest. Foss. Ireland' 1844, pl. xxii, fig. 12 & p. 131.

[2] Proc. Bristol Nat. Soc. n. s. vol. x (1903) pl. ii, fig. 1.

hinge-line, and more attenuated umbo in the pedicle-valve; and also by the absence of a well-marked fold and sinus.

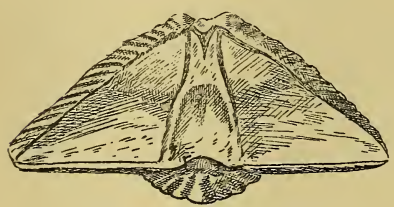
The occurrence of this form, so closely resembling the index-species of the *Seminula* Zone in the South-Western Province, at a much lower level in the North-Western Province is of considerable interest.

Horizon and locality.—*Athyris-glabristria* Zone (chiefly in the upper portion of this zone). The specimen figured is from the *Camarotœchia-proava* Band at the summit of the *Solenopora* Subzone, at Low Meathop, Arnside District.

Spiriferina laminosa M'Coy. (Pl. LI, figs. 7 *a*–7 *e* & text-fig. 7.)

The form figured here appears to belong to M'Coy's species; but his original figure is too poor for precise comparison, and the type-specimen is unfortunately not preserved in the Griffith Collection at Dublin, although search has been made for it. It is certainly not a *Syringothyris*, as specimens when rubbed down show only a single plate in the delthyrium of the pedicle-valve (text-fig. 7). The shell is characterized by the abundance of coarse punctations which are conspicuous along the hinge-line, as well as in other portions of the shell.

Fig. 7.—*Specimen of* Spiriferina laminosa, *showing the delthyrium of the pedicle-valve (rubbed down).*



[Twice the natural size.]

This form is very characteristic of the *Productus corrugato-hemisphericus* Zone in the Ravenstonedale District, being found abundantly both in the Ashfell Sandstone in the lower portion of the zone, and in the Bryozoa Band at the summit of the zone. The specimen figured is from the Lower *Pr. corrugato-hemisphericus* Zone near the summit of the Ashfell Sandstone, Ravenstonedale District.

Appendix I.

Description of the Teeth of Two New Species of Fishes from the Lower Carboniferous Rocks of the North-Western Province.

By A. Smith Woodward, LL.D., F.R.S., Sec.G.S.

Deltodus garwoodi, sp. nov. (Pl. LII, figs. 2, 3 *a*, & 3 *b*.)

Specific characters.—'Upper' dental plate narrow, triangular in shape, and scarcely curved; antero-lateral and postero-lateral borders nearly straight, the inner border bulging downwards

in its anterior half. Antero-lateral half of the coronal face raised into a prominent round ridge, which is partly subdivided by transverse constrictions into a few large rounded bosses; postero-lateral half flattened, curving a little upwards at the postero-lateral border.

Remarks.—This species is known only by two satisfactorily preserved 'upper' dental plates and a few fragments. The type-specimen (B.M. P 10335) measures 12 mm. in width at its inner border, while the second specimen is somewhat larger. In the former five distinct bosses are seen on the rounded antero-lateral ridge, and there would probably be a sixth at the apex, which is broken away. In both cases the coronal face is much abraded, so that the punctations of the dentine, below the original surface, are conspicuous; but in the larger specimen there are still traces of sigmoidally-curved lines extending from the grooves between the antero-lateral border: these suggest that the dental plate results from the fusion of *Helodus*-shaped teeth in which the coronal eminence occupied the anterior half.

D. garwoodi, which is named after its discoverer, differs from all other known species of the genus in the coarse beading of the antero-lateral eminence of its dental plate, the relative evenness of its postero-lateral half, and the slightness of its curvature. A fragment from the St. Louis Limestone of Illinois, which has been referred to *D. intermedius*,[1] perhaps approaches it most closely.

Horizon and localities.—*Solenopora* Sub-zone. *Archæocidaris* Bed, Shap Abbey, Shap; and *Vaughania-cleistoporoides* Band, Stone Gill, Ravenstonedale.

Cochliodus virgatus, sp. nov. (Pl. LII, figs. 4 *a* & 4 *b*.)

Specific characters.—Anterior dental plate scalene-triangular in shape; its sharp oblique coronal ridge divides the surface into two equal areas, of which the postero-lateral is smooth and slopes gradually downwards to the border, while the antero-lateral is strongly ridged, with a tendency to the branching of at least one ridge. Postero-lateral border slightly crimped.

Remarks.—The anterior dental plate of *Cochliodus* often exhibits a tendency to bear radiating ridges on its antero-lateral extensions, but the new tooth is unique in the strength of this ridging. The specimen described also differs from all other known teeth of *Cochliodus*; but it resembles *Psephodus*, in the crimping of at least part of the border.

Horizon and locality.—*Vaughania-cleistoporoides* Band, *Solenopora* Sub-zone. Stone Gill, Ravenstonedale.

[1] A. H. Worthen & O. St. John, Geol. Surv. Illinois, vol. vii, Geol. & Pal. (1883) pl. ix, fig. 15.

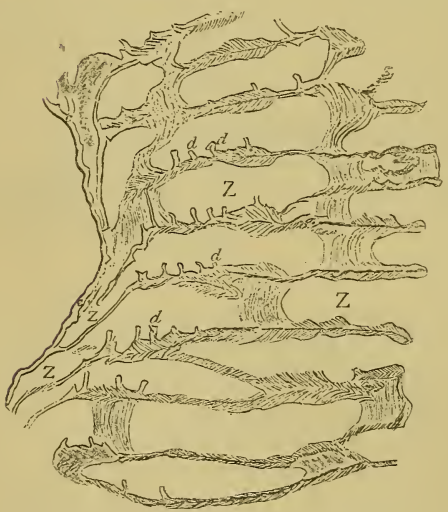
Appendix II.

Description of some New Forms of Trepostomatous Bryozoa from the Lower Carboniferous Rocks of the North-Western Province. By Madeline Munro, B.Sc.

Stenophragma, gen. nov.

Zoarium ramose or irregular, lobate and folded; branches generally hollow and lined by an epizoarium; zoœcia of varying size, the largest sometimes occupying distinct monticules at the surface; periodical thickening of the walls in the mature region well marked in many species; diaphragms present in the mature region, incomplete and very narrow, only attached to the proximal walls; acanthopores present or absent; no mesopores, but cells much smaller than the average are observed occasionally.

Fig. 8.—*Longitudinal section of a branch of* Stenophragma lobatum, *consisting of only one layer, showing strong epizoarium* (e), *zoœcia* (z), *diaphragms* (d), *in the mature region, and the characters of the walls.* × *about 20 diameters.*



[Two of the diaphragms in the above figure are wrongly shown open at the tip.]

Stenophragma lobatum, gen. et sp. nov. (Figs. 8–10.)

Zoarium composed of one to three layers, each having a thickness of 1 to 2·5 mm., epizoarium strong and wrinkled; branches hollow, irregularly lobate or folded, having a diameter of from 5 to 20 mm.; zoœcial apertures usually polygonal, sometimes subcircular; three to four ordinary zoœcia occupy 1 mm.; monticules quite conspicuous, each occupied by eight or more zoœcia nearly half as broad again as the rest, the centres of these groups being at distances of 4 to 5 mm. from one another. Zoœcial tubes thin-walled and oblique at first, then making an angle of about 120° they proceed directly to the surface, the walls at the same time becoming much thicker and the tubes broader; the walls are periodically constricted. The numerous narrow crescentic diaphragms arise at very constant levels in neighbouring zoœcia, and always from what were the

Fig. 9.—*Tangential section of* Stenophragma lobatum: *showing the polygonal and rounded outlines of the zoœcia* (z), *many of which are furnished with narrow diaphragms* (d); *also great variation in the thickness of the walls.* × *about 20 diameters.*

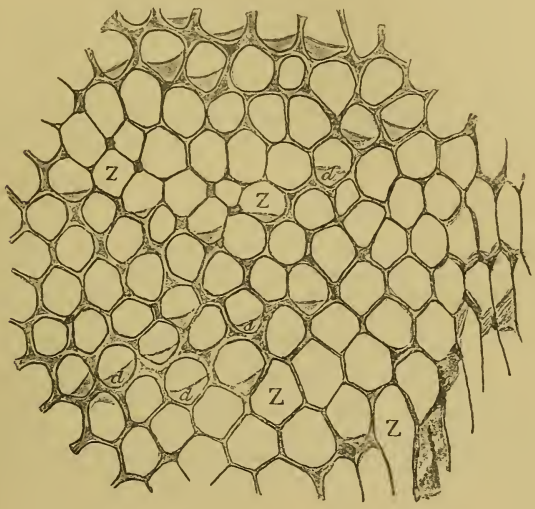
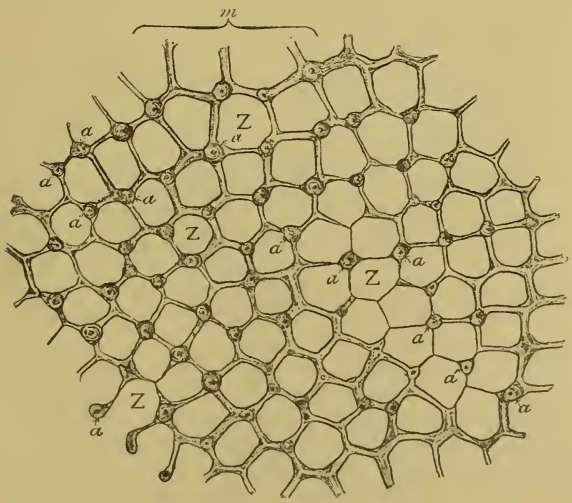


Fig. 10.—*Tangential section of* Stenophragma lobatum, *showing the distribution of the numerous acanthopores* (a), *and passing through a portion of a monticule* (m). × *about 20 diameters.*



proximal or lower walls of the zoœcial tubes (assuming, as seems probable, that the branches were erect); most of the diaphragms are curved inwards and even back towards the lower walls; usually they are thickened along the inner margin: they never extend more than a third of the way across the zoœcial tubes.

The divisional line between adjoining zoœcia, as seen in section, is rarely well-marked, and the laminated structure of the walls is clearly seen in longitudinal sections. Many, but not all, of the junction-angles are occupied by strong acanthopores; these in well-preserved specimens appear as blunt spines at the surface.

Horizon and locality.—*Solenopora* Sub-zone. Ravenstonedale.

Stenophragma grandyense, sp. nov.

The genus *Stenophragma* is further represented by a single large and well-preserved specimen from Grandy Quarry, near Shap. This specimen, consisting of a hollow cylindrical branch, differs conspicuously from those constituting the species just described in the absence of acanthopores, the larger size of the zoœcia, the much greater thickness of their walls in the mature region, and the circular or oval outlines of the zoœcia, as seen in tangential sections. The periodical constrictions of the wall in the peripheral region are much more marked though less numerous; the diaphragms are somewhat thicker, and gently curved towards the epizoarium throughout their width, tapering slightly at the inner margin. The divisional lines between adjoining zoœcia are frequently occupied by a crowded but usually single series of small dark spots, many of which (when magnified) present the appearance of minute tubuli, running parallel with the length of the zoœcial tubes.

In all other characters this specimen is essentially similar to those from Ravenstonedale, and the name *Stenophragma grandyense* is suggested for its reception.

Other specimens from Humphrey Head and Great Rundal Beck (Upper *Dibunophyllum* Sub-zone in both localities) appear to be referable to the same species. Unfortunately, the material available is scarce, and the immature region is crushed in parts; however, all the sections show a close resemblance, both in structure and in dimensions, to *St. grandyense*. The excellent preservation of one of the specimens from Humphrey Head probably accounts for the fact that it is only in sections of this one that acanthopores can be observed; they are few in number and irregularly distributed, occurring singly at some of the junction-angles which are not occupied by a cluster of dark spots.

A solitary, but large and well-preserved specimen from Ashfell, near the summit of the Gastropod Beds, will probably necessitate the foundation of an additional new species for its reception.

This consists of part of a long hollow cylindrical branch having a diameter of 12 mm. The zoarium varies in thickness from 2 mm. to 4·5 mm., and is lined by a strong wrinkled epizoarium;

the immature region is very narrow, but not constant in extent. The zoœcia are large, though not uniform in size: about thirty occupy 1 cm.; the largest occur in groups, and originally they may have constituted monticules at the surface, but this is somewhat worn; the apertures are polygonal. Cells with apertures much smaller than the average occur occasionally, and especially among the largest zoœcia. The moniliform thickening of the walls is very pronounced, occurring at frequent but variable distances throughout the peripheral region, though at constant levels in all parts of the zoarium. Diaphragms are few, very narrow, often thickened along the inner edge; almost invariably one occurs at the point where the zoœcial walls become thickened, and bend outwards to proceed directly to the surface. Acanthopores of moderate size occur singly at many of the junction-angles.

This specimen is further characterized by the possession of numerous structures of an unusual kind, which may prove to be mesopores. They appear to have been cut off from the zoœcial cavities by outgrowths from the zoœcial walls; they occur singly and in small clusters at many of the junction-angles.

The genus *Stenophragma* closely resembles *Anisotrypa*, Ulrich, and *Tabulipora*, Young, in many characters; but it differs from both, in having narrow crescentic diaphragms attached only to the proximal portion of the circumference of the zoœcial walls, instead of centrally perforated diaphragms.

It seems advisable to alter one sentence in the description of the family Batostomellidæ, Ulrich, to read thus:—

'diaphragms in the peripheral region often centrally perforated or merely crescentic,'

in order that the genus may be included in it.

[As these notes are passing through the press we learn from the Geological Survey Memoir on the 'British Carboniferous Trepostomata,' by Dr. G. W. Lee, issued on May 12th, 1912, that other new species, agreeing in all essential characters with those described above, have been placed in the genus *Tabulipora* Young, in Section B, founded for their reception, since they differ from the typical species of the genus as originally founded, in that

'the perforation of the tabulæ occupies a lateral position, distal in relation to the general direction of growth.'

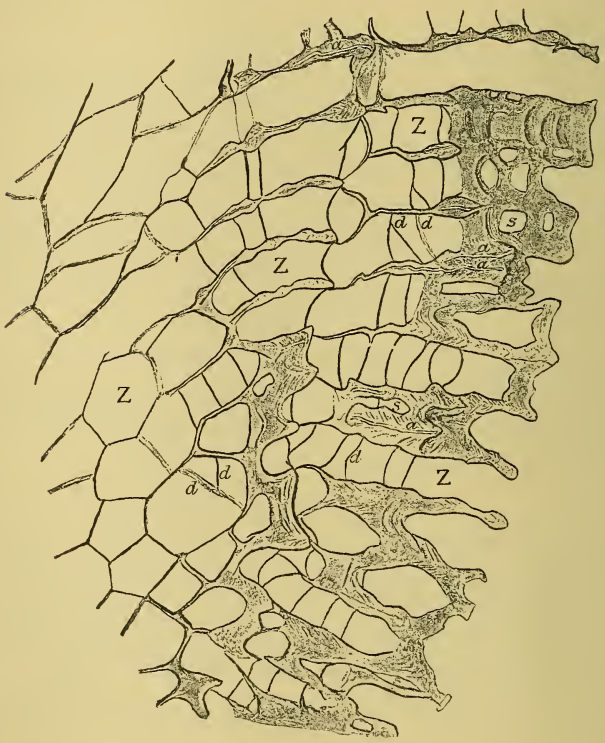
In other words, the diaphragms are attached to the proximal or lower walls of the zoœcia.]

STENOPORA COMPACTA, sp. nov. (Figs. 11 & 12, pp. 578–79.)

Zoarium ramose; branches solid, robust, often 8 mm. in diameter; frequently dichotomizing, the branches thus formed only slightly narrower than the main branch; many-layered, those layers which are fully developed having a thickness of 2 mm. in

the mature region. Zoœcia prismatic and thin-walled in the axial region, diverging gently from an imaginary central axis to open directly at the surface; usually, eight to ten zoœcia occupy 5 mm. in all parts of the zoarium; apertures rounded and large; walls

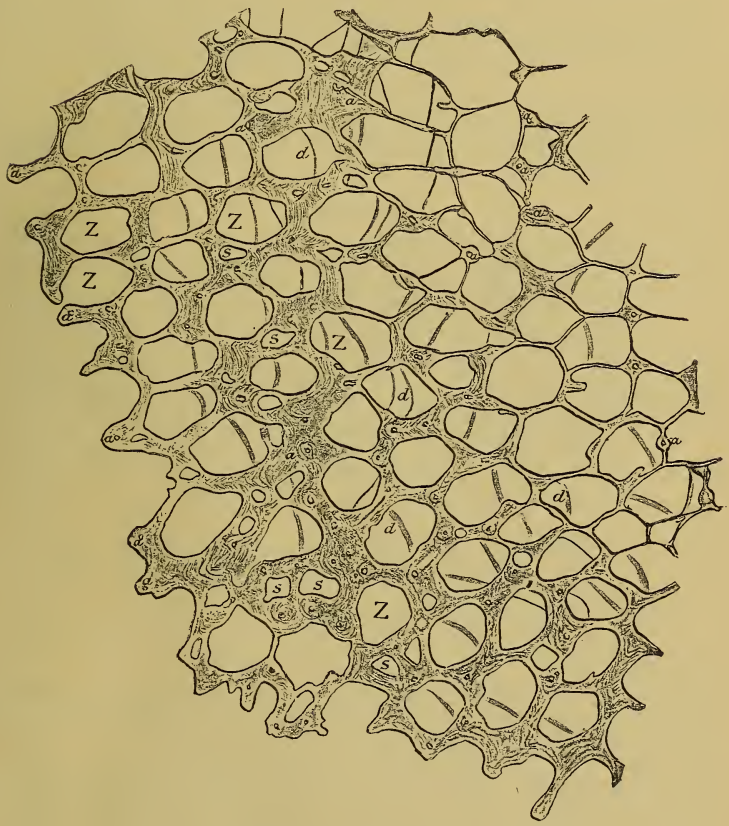
Fig. 11.—*Longitudinal section of a branch of* Stenopora compacta, *sp. nov., composed of two layers: showing zoœcia* (z) *traversed by complete diaphragms* (d), *small cells, possibly mesopores* (s), *acanthopores* (a), *and the characters of the walls in the mature and the immature regions.* × *about 20 diameters. (From the Bryozoa Band, Weather Hill, Shap District.)*



unequally thickened in the mature region, but seldom sharply constricted. The zoœcia are traversed by thin, complete diaphragms, which are rare in the axial region but numerous in the mature zone, seldom being separated by distances greater than their own diameter; the majority are straight and horizontal, but some are very oblique, others curved, and often an oblique and an horizontal one appear to coalesce or have a common origin on one side. Small cells, often irregularly moniliform and without diaphragms, occur singly at many of the junction-angles. Acanthopores few, the

majority small and inconspicuous. In those parts of the zoaria where the mature region is very narrow, the zoœcia often open

Fig. 12.—*Tangential section through the mature region of* Stenopora compacta, *showing the sub-polygonal and rounded outlines of the zoœcia* (z), *small cells, possibly mesopores* (s), *acanthopores* (a), *and marked variation in the thickness of the walls.* × *about 20 diameters.*



[The diaphragms should be shown attached to the zoœcial walls at all points.]

obliquely at the surface, and small cells (which may be mesopores) are not seen.

Horizon and localities.—Bryozoa Band, top of the *Nematophyllum-minus* Sub-zone; Roman Fell, Weather Hill, and Orton Knott. The best-developed examples are from Weather Hill, but the greatest number are from Roman Fell.

EXPLANATION OF PLATES XLIV–LVI.

Plate XLIV (facing p. 486).

Fig. 1. Shap-Abbey Cliff, *Solenopora* Sub-zone. (The figure points to the Lower *Solenopora* Band; the *Proava* Band lies at the top of the cliff.)
2. Halton Green, Arnside District. Knoll-reef breccia (D_2-D_3). (See p. 515.)

Plate XLV (facing p. 512).

Fig. 1. Trowbarrow Quarry, Silverdale, showing the vertical beds of D_1.
2. Middlebarrow Quarry, Silverdale, showing the thrust-plane in D_1.

Plate XLVI (facing p. 518).

Fig. 1. Fold in the *Thysanophyllum* Band, Hall-Head Hall, Kendal.
2. Pseudobreccia and 'Stick Bed,' Lower *Dibunophyllum* Sub-zone, Chapel Island, Furness. (See p. 533.)

Plate XLVII.

Fig. 1. Transverse section of *Solenopora garwoodi* (MS. Hinde), from the *Solenopora* Sub-zone. Stone Gill, Ravenstonedale District. × 40. (See p. 459; also Pl. XLIX, fig. 1.)
2. A section of a typical calcareous alga from the Algal Layer, at the base of the *Seminula-gregaria* Sub-zone. Near Wath, Shap District. × 40. (See p. 462.)
3. Section of a 'spotted' bed, showing the arrangement of the sand-grains round a dark calcareous nucleus, from the Lower *Dibunophyllum* Sub-zone. Great Rundal Beck, Pennine District. × 12. (See p. 476.)
4. Section of porcellanous rock showing *Calcisphæræ*, etc., from the Bryozoa Band. Lyvennet Beck, Shap District. × 45. Inset: *Calcisphera* cf. *fimbriata* Williamson. (See p. 474.)

Plate XLVIII.

Fig. 1 *a*. *Carruthersella compacta*, gen. et sp. nov. Natural size. *Seminula-gregaria* Sub-zone. Meathop, Arnside District. (See p. 555.)
1 *b*. The same. × 3.
1 *c*. Section through the base of the cup from the same specimen, showing the structure of the central area and the outer zone of vesicular tissue. × 2.
1 *d*. The same. Longitudinal section. × 3.
Figs. 2 *a*–2 *c*. *Lophophyllum meathopense*, sp. nov. Serial sections. Natural size. *Seminula-gregaria* Sub-zone. Meathop. (See p. 557.)
Fig. 2 *d*. *L. meathopense*. Another specimen. Natural size.
2 *e*. Longitudinal section of the same, natural size.
Figs. 3 *a* & 3 *b*. *Carcinophyllum simplex*, sp. nov. Natural size. Serial sections. *Seminula-gregaria* Sub-zone. Meathop. (See p. 556.)
Fig. 3 *c*. *C. simplex*. Another specimen. Natural size. Marton, Furness District.
4 *a*. *C. simplex*. Natural size. Section through the cup of a large specimen. *Seminula-gregaria* Sub-zone. Meathop.
4 *b*. Longitudinal section of the same, natural size.
5 *a*. *Lophophyllum vesiculosum*, sp. nov. Natural size. *Seminula-gregaria* Sub-zone. Meathop. (See p. 559.)
5 *b*. Longitudinal section of the same.
Figs. 6 *a* & 6 *b*. *Campophyllum ciliatum*, sp. nov. Serial sections, natural size. *Seminula-gregaria* Sub-zone. Meathop. (See p. 561.)
Fig. 6 *c*. Longitudinal section of the same, natural size.
7. *Vaughania cleistoporoides*, gen. et sp. nov. Natural size. *Solenopora* Sub-zone. Ravenstonedale District. (See p. 564.)

Plate XLIX.

(All the figures are of the natural size.)

Fig. 1. *Solenopora garwoodi* MS. Hinde. Lower *Athyris-glabristria* Zone. Shap-Abbey Cliff. (See p. 459.)

2 *a*. *Thysanophyllum pseudovermiculare* (M'Coy). Natural size. Showing the mode of budding. Underbarrow Road, Kendal District. (See p. 562.)

Figs. 2 *b* & 2 *c*. Horizontal sections of the same. Rosgill, Shap District.

Fig. 2 *d*. Longitudinal section of the same.

3. *Caninia subibicina* M'Coy. Horizontal section, natural size. From M'Coy's type-specimen in the Sedgwick Museum, Cambridge. *Michelinia* Zone, Kendal District. (See p. 561.)

4. *Zaphrentis koninckı*, forma *kentensis* nov. *Michelinia* Zone. Gascow, Furness District. (See p. 561.)

Figs. 5 *a* & 5 *b*. *Lophophyllum fragile*, sp. nov. *Michelinia* Zone. Arnside Shore, Arnside District. (See p. 558.)

Plate L.

(All figures are of the natural size.)

Fig. 1. *Clisiophyllum multiseptatum*, sp. nov. Large specimen, from the *Cl.-multiseptatum* Band, *Michelinia* Zone. Gascow, Furness District. (See p. 560.)

Figs. 2 & 3. *Cl. multiseptatum*. Younger specimen. Arnside District.

Fig. 4 *a*. *Cl. multiseptatum*. Another specimen, showing the thickened septa.

4 *b*. Longitudinal section of the same.

5. *Cyathophyllum multilamellatum* (M'Coy). Section of type-specimen in the Sedgwick Museum, Cambridge, from Arnside. (See p. 562.)

6. *C. multilamellatum*. *Michelinia* Zone. Arnside.

7. *C. multilamellatum*. Another specimen. Same locality.

Figs. 8 *a* & 8 *b*. *Diphyphyllum* aff. *lateseptatum* M'Coy. Base of the *Productus-corrugato-hemisphericus* Zone. Blackstone Point, Arnside. (See p. 563.)

9 *a* & 9 *b*. *Lophophyllum ashfellense*, sp. nov. Ashfell Sandstone, Ravenstonedale. (See p. 559.)

Plate LI.

(Figures 1–7 are of the natural size.)

Figs. 1 *a*–1 *c*. *Camarotœchia proava* Phill. *Camarotœchia-proava* Band. *Solenopora* Sub-zone. Ravenstonedale District. (See p. 567.)

Figs. 2 *a* & 2 *b*. *Rhynchonella (Pugnax) fawcettensis*, sp. nov. *Productus globosus* Band. *Seminula-gregaria* Sub-zone. Shap District. (See p. 568.)

Figs. 3 *a* & 3 *b*. *Productus rotundus*, sp. nov. Base of the *Seminula-gregaria* Sub-zone. Shap District. (See p. 569.)

Figs. 4 *a* & 4 *b*. *Productus globosus*, sp. nov. Base of the *Seminula-gregaria* Sub-zone. Shap District. (See p. 568.)

Fig. 5. *Seminula gregaria* M'Coy. *S.-gregaria* Sub-zone. Shap District. (See p. 571.)

Fig. 6. *Seminula* aff. *ficoidea* Vaughan. *Solenopora* Sub-zone. Meathop. (See p. 571.)

Figs. 7 *a*–7 *e*. *Spiriferina laminosa* M'Coy. Lower *Productus-corrugato-hemisphericus* Zone. Ashfell Sandstone, Ravenstonedale District. (See p. 572.)

Fig. 8. *Productus* cf. *maximus* M'Coy. Lower *Dibunophyllum* Sub-zone. Long Fell, Pennine District. About two-thirds of the natural size. (See p. 570.)

PLATE LII.

(All figures are of the natural size.)

Figs. 1 *a* & 1 *b*. *Spirifer pinskeyensis*, sp. nov. From below the Shap Basement Conglomerate, Pinskey Gill, Ravenstonedale District. (See p. 570.)

Fig. 2. *Deltodus garwoodi*, sp. nov. *Solenopora* Sub-zone (*Vaughania-cleistoporoides* Band). Stone Gill, Ravenstonedale District. (See p. 572.)

Figs. 3 *a* & 3 *b*. *Deltodus garwoodi*. Same horizon. Shap-Abbey Cliff, Shap District.

Figs. 4 *a* & 4 *b*. *Cochliodus virgatus*, sp. nov. *Solenopora* Sub-zone (*Vaughania-cleistoporoides* Band). Stone Gill, Ravenstonedale District. (See p. 573.)

PLATE LIII.

Geological map illustrating the Lower Carboniferous rocks of the Shap and Ravenstonedale Districts, on the scale of 1 inch to the mile, or 1 : 63,360.

PLATE LIV.

Geological map illustrating the Lower Carboniferous rocks of the Kendal, Kirkby Lonsdale, Arnside, and eastern portion of the Grange Districts, on the scale of 1 inch to the mile, or 1 : 63,360.

PLATE LV.

Geological map illustrating the Lower Carboniferous rocks of the Furness and western portion of the Grange Districts, on the scale of 1 inch to the mile, or 1 : 63,360.

PLATE LVI.

Fig. 1. Section across the Shap District. Scales: horizontal, 6 inches = 1 mile; vertical, 1 inch = 850 feet.

2. Section across the Ravenstonedale District. Scales, the same as fig. 1.

3. Generalized section across the Furness, Grange, and North Kendal Districts. Horizontal scale: 1 inch = 1 mile; vertical scale: 1 inch = 850 feet.

DISCUSSION.

Dr. MARR said that he had been over much of the ground with the Author, and desired to express his admiration of the thorough way in which the work had been done. The fact that towards the end of his investigations the Author was able to view a section which he had not previously visited, and, after a very brief inspection, could state what was to be found there, was a proof of the accuracy of the work. The speaker was interested in the beds at Pinskey Gill. According to the Geological Survey map, the conglomerate apparently overlying the *Spirifera*-bearing beds was the 'Basal Conglomerate' faulted into that place. The Author suggested a different interpretation: the Devonian age of those beds was suggested, but not stated. It need not be assumed that because no Devonian strata had hitherto been recorded in the area, they must necessarily be absent. Lastly, the speaker called attention to the old view that the Lake District was an island in Lower Carboniferous times; he thought that the evidence brought forward in the paper was against that view.

Dr. Vaughan congratulated the Author on so successful a termination to his protracted labours, on the thoroughness of his work, and on the well-balanced presentation of the many facts of interest. The sequence in and above the '*Michelinia* Bed' of Arnside and above the '*pseudovermiculare* bed' of Brigsteer, near Kendal, appeared to agree exactly with the sequence from C_2 through S and D in the type-Province. Considering the very small total thickness from the base of the '*pseudovermiculare* bed' to the base of S_1 at Brigsteer; and remembering also that white oolite, similar to that above the bed, occurred at the top of C_2, not only at many points of the South-Western Province, but also in Belgium and Northern France, it seemed unlikely that the '*pseudovermiculare* bed' itself could lie beneath C_2. Below this bed, at Brigsteer, occurred no great thickness of dolomite, but the Author had presented a very different picture of his type-sections at Ravenstonedale and Shap. Here there was some 1200 feet of more or less dolomitic rock—rivalling the Grande Dolomie of Namur—from which, by dint of oft-repeated attacks, he had obtained a most valuable series of brachiopods. Lastly, in regard to the '*Spirifer-pinskeyensis* Beds,' a further scrap of evidence favouring the suggestion made by the Author that these beds were Devonian, was the fact that Spirifers possessing a similar type of ribbing, combined with the peculiar mesial fold, were common only in Devonian rocks (compare *Sp. oweni* Hall and *Sp. granulosus* Conrad—both from the Hamilton Beds of North America). It might therefore be that, at Ravenstonedale, deposits were only interrupted from the latest Devonian to early *Zaphrentis* time: at Brigsteer the gap was greater.

Mr. R. G. Carruthers remarked on the great interest of this important paper. Not the least interesting of the many points raised lay in the instance cited of a transgression of faunal across lithic lines, as shown by the relationship of the *Michelinia* Beds to the Ashfell Sandstone. Correlation with standard areas was, to some extent difficult, owing to the difference of faunal facies. Nevertheless, such a fact was of great interest to the evolutionist, as it gave hope that in this northern tract gaps might be filled in the life-history of certain gentes, of which hitherto we possessed very imperfect knowledge.

The assignment of the lowest beds to horizon γ was supported by the statement that the *Zaphrentis-koninckı* Bed lay some 1200 feet above this base. There were strong reasons for considering that this species was, genetically, short-lived, and the assemblage found in Ravenstonedale was of practically the same evolutionary standard as that found in C_2 of the South-Western Province.

Mr. J. Allen Howe welcomed the paper, and said that he was particularly struck with the evidence that the Author had obtained of the important development of algæ; he was strongly of opinion that this group of organisms had often played a large part in the formation of some of the Carboniferous limestones: its significance had been rather overlooked.

The small fold between undisturbed beds briefly described by the Author was a very interesting feature, about which he (the speaker) would be glad to learn more. He was acquainted with what appeared to be similar cases in the limestones of Pendle Hill, and near Ashford in Derbyshire.

That the spotting in the 'spotted' limestone was in some way connected with the presence of sand-grains was new to the speaker; in all the examples that he had examined, from South and North Wales, Derbyshire, and elsewhere, he had not observed any associated sand-grains.

It was with great diffidence that he said a word about zonal fossils, but he could not help feeling that it would have been more convenient if the zonal forms adopted had been the same as those established in the South-Western region. Quite possibly this was not practicable, if so it was a matter of considerable interest; still, the practice of selection of locally abundant fossils as zone-indicators would tend to obscure the facts of correlation for the ordinary student.

Mr. Cosmo Johns remarked on the value and interest of the paper, and said that he was in general agreement with the Author. He was particularly pleased with the value attached to the bands, chiefly faunal, as marking definite horizons. Of the great value of these distinctive bands in field-work there could be no question, provided that they were not used beyond the area where their value had been established. He would also agree with the Author in considering the dolomitization of the lower limestone-beds as being contemporaneous: their restriction to definite horizons was so clear that it would invalidate any other conclusion. He further agreed with the Author that beds of Tournaisian age, that was, lower than the C_2S level which forms the logical base to the Viséan, occur in Ravenstonedale. He would, however, differ from the Author in suggesting probable equivalents with the zonal divisions made by Dr. Vaughan in the South-Western Province and in Belgium. The beds with *Cyrtina septosa*, a maximum of *Cyathopyllum murchisoni*, and characterized by the pseudo-breccia, would, in the Yoredale country and South Wales, come in at the base of D_1 and not at the top. The division of the whole succession into a series with and a series without *Lithostrotion* was hardly precise enough, and a definite division into Tournaisian and Viséan would appear to be necessary. If this were done, the line would be drawn below and not above the *Michelinia-megastoma* level, and might even include the beds with *Thysanophyllum pseudovermiculare*, below which the most marked lithological change seemed to occur.

The transgression of the faunal lines across the lithological lines in the short distance from Ravenstonedale to Shap, as mentioned by the Author, was so startling that comment must be reserved until the whole of the evidence had been published. It was possible that a complication had been introduced into the reading of the structure of the Shap-Ravenstonedale area by assuming that the whole of the Carboniferous rocks were laid down over what is now the Lake-

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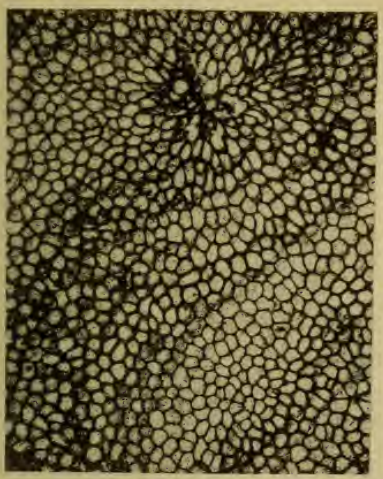

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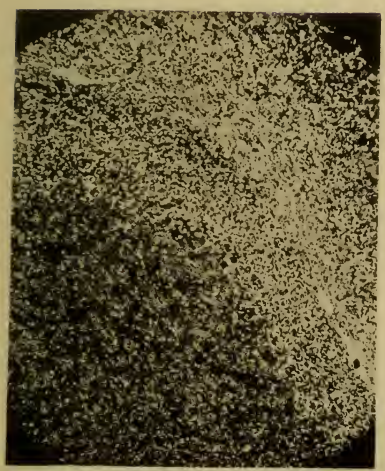

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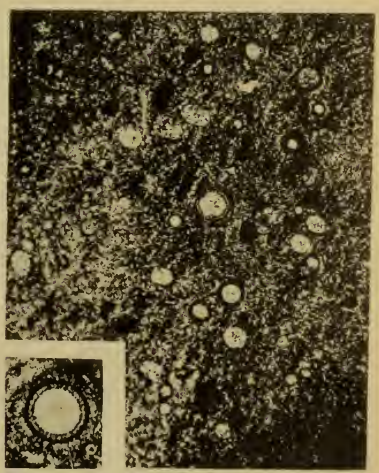

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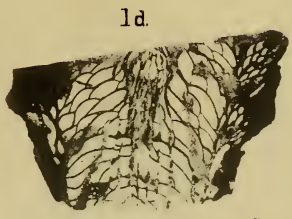
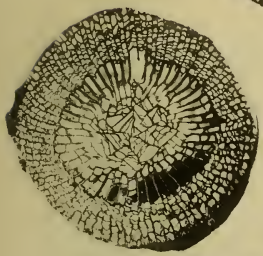
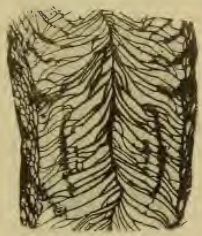
E. J. G., Photo.

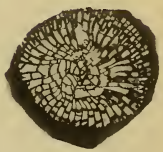
Bemrose, Collo., Derby

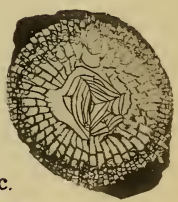
SECTIONS OF FOSSILS AND ROCKS
FROM THE CARBONIFEROUS LIMESTONE SERIES.

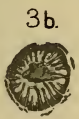


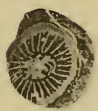


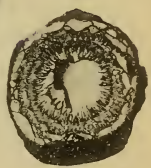


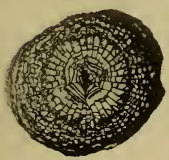


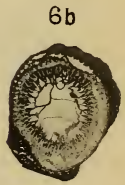












E.J.G., Photo.

Bemrose, Collo., Derby

CARBONIFEROUS LIMESTONE CORALS.

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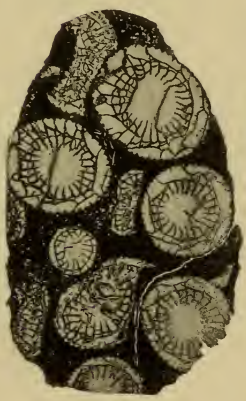
3.

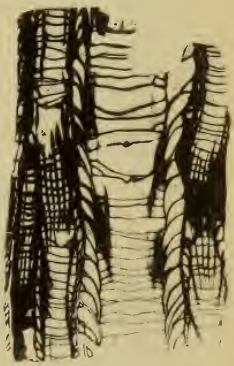
4.

2a.

2b.



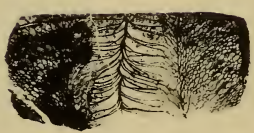
2d.



2c.

5a.

5b.



E.J.G. & J. W. Tutcher, Photo. Bemrose, Collo., Derby.

CARBONIFEROUS LIMESTONE CORALS.

1.

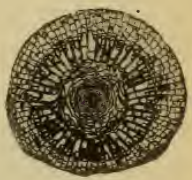
3.

5.

4b.

2

4a.



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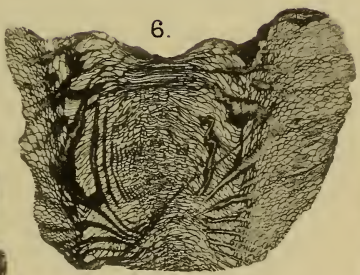

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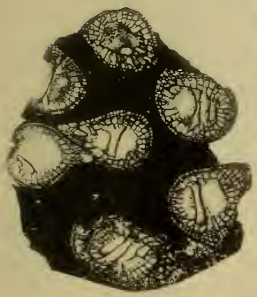
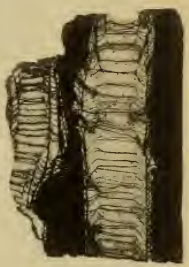


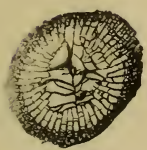
8b.



7.

9b.

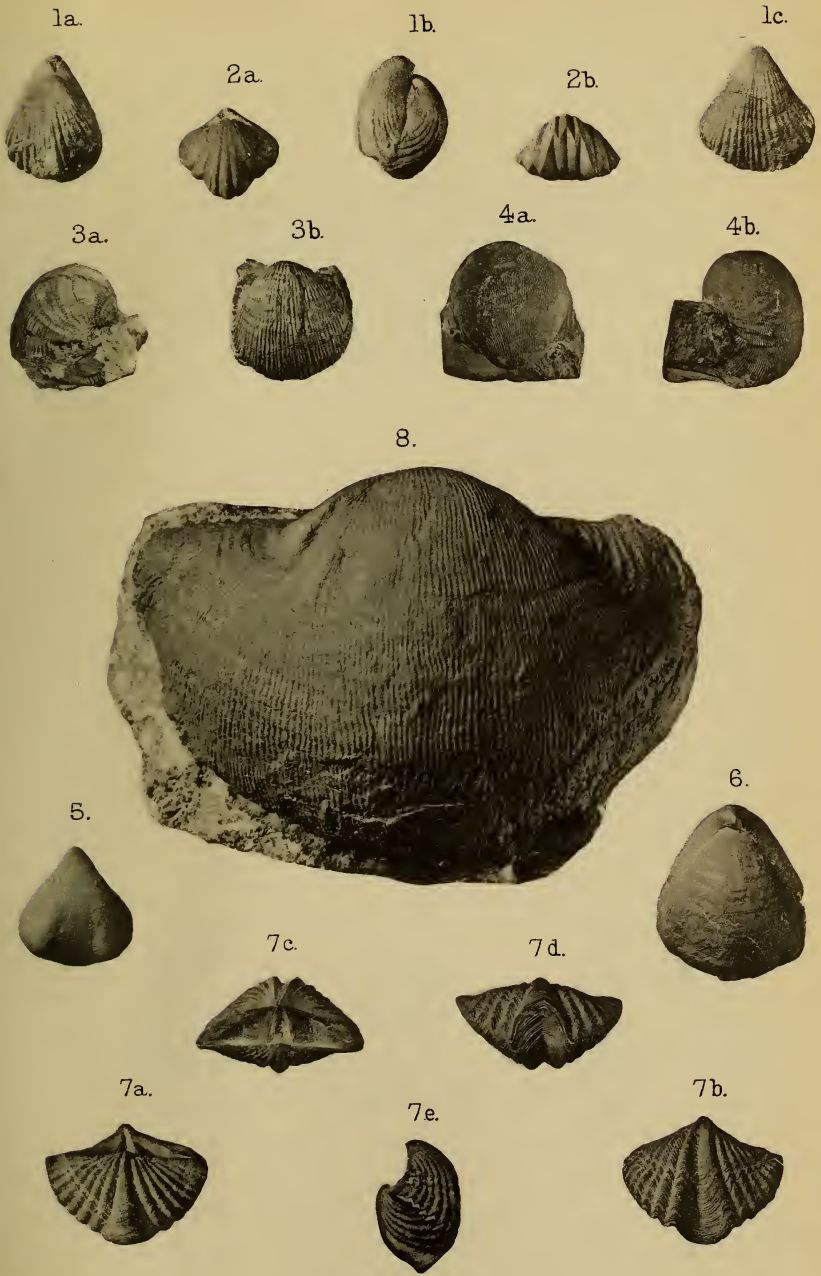
9a.



E.J.G. Photo.

Bemrose, Collo., Derby.

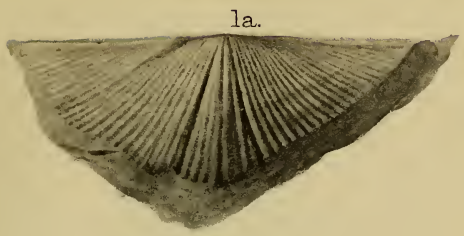
CARBONIFEROUS LIMESTONE CORALS.

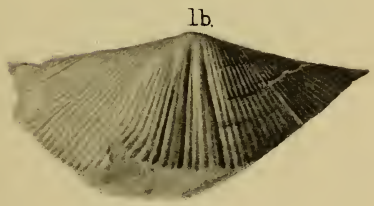


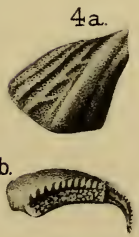
J. W. Tutcher, Photo.

Bemrose, Collo., Derby.

CARBONIFEROUS LIMESTONE BRACHIOPODS.







G.M. Woodward, del.

Bemrose. Calto., Derby.

SPIRIFER, DELTODUS, AND COCHLIODUS.

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GEOLOGICAL MAP ILLUSTRATING THE LOWER CARBONIFEROUS ROCKS OF THE SHAP & RAVENSTONEDALE DISTRICTS.

BY E. J. GARWOOD, M.A., V.P.G.S.

Permian Rocks

Ordovician & Silurian Rocks

River Eamont
Thorp
Tirril
Clifton
Askham
Lowther
Helton Flecket
Whale
River Lowther
Great Strickland
Morland
LINE OF SECTION
Kings Meaburn
APPLEBY
Burrells
Little Strickland
Teth Beck
Knipe Scar
In Scar
Out Scar
Stragill
Bampton
Sweet Hayton
High Suds
831
Reagill
862
Wintertarn Farm
Byestead
Moulds Meaburn
Wickerslacke Moor
Shap Abbey
Shap
Crosby Ravensworth
Hardendale Farm
Shap Station
Hardendale Nab
The Nab
Potter's Farm
Granity Quarries
Oddendale
Lyvennet Beck
Bank Moor
Great Asby
1153
Seal How
Gathorn Plain
Bearham Quarry
Gulpit Sike
Shap Thorn
1315
Long Scar Pike
Orton Scar
Great Asby Scar
Little Asby
Shap Wells
Birk Beck Fell
Common
1352
Orton Knott
Little Asby Scar
Orton
Scandal Beck
Crosby Garrett Fell
Kirkby Stephen Station (N.E.Ry)
Kirkby Stephen (Midland Station)
D. Llangollensis Beds
Waitby Common
Lanehead Quarry
Blue Quarries
Hazelbeck
Fawcett Mill
Ravenstonedale Moor
Rogan
Kelleth
Newbiggin Station
Wath
Gaisgill Station
Greenside
Ravenstonedale
Shawmire
Piper Hole Farm
Brunt Hill
Artlegarth Beck
DENT FAULT

(The small arrows indicate dips)

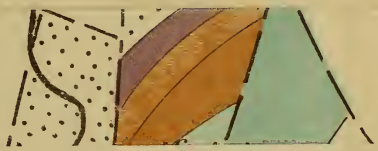
INDEX OF COLOURS

- Upper Saccamma band. Grenulla band
- Calcaireides band
- Lower Bryozoa Band
- Nematophyllum-minus SUB-ZONE
- Cyrtina-carbonaria SUB-ZONE
- Gastropod Beds or Pred. cor-hem. Zone undivided
- Sandstone Transgression
- Brownber Pebble Bed
- Seminula-gregaria SUB-ZONE
- Dibunophyllum band
- Plicatulus band. Algal layer at base
- Solenopora SUB-ZONE
- Shap Conglomerate with felspar fragments
- Pinskey-Gill Beds

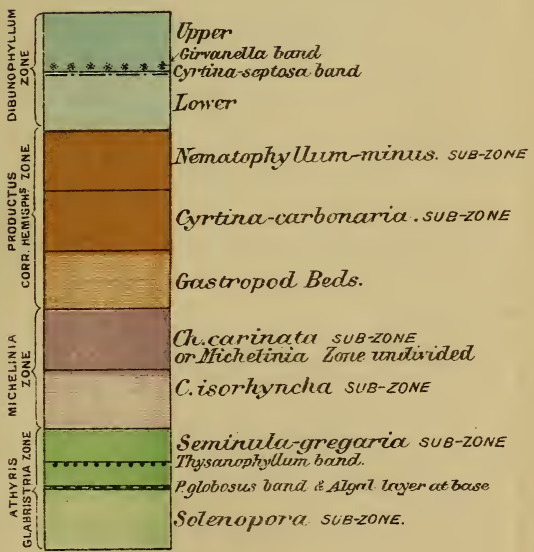
DIBUNOPHYLLUM ZONE; PRODUCTUS CORA-HEMIPHYA ZONE; RICHI-GIGANTEUS ZONE; ATHYRIS

Scale of One Inch to One Mile

Weller & Graham Ltd Litho London



INDEX OF COLOURS



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GEOLOGICAL MAP ILLUSTRATING THE LOWER CARBONIFEROUS ROCKS OF THE KENDAL, KIRKBY LONSDALE, ARNSIDE & EASTERN PORTION OF THE GRANGE DISTRICTS

BY E. J. GARWOOD M.A., V.P.G.S.

Scale of One Inch to One Mile. 0 1 2 3 4 Miles

LINE OF SECTION

WHIT BARROW BLOCK

YEWBARROW BLOCK

MILNTHORPE SANDS

KENDAL

KIRKBY LONSDALE

BURTON IN KENDAL

MORECAMBE BAY

Upper Carboniferous Rocks

(The small arrows indicate dips)

INDEX OF COLOURS

- Upper
  - Girvanella band
  - Cyrtina septosa band
- Lower
- Neomatophyllum-minus sub-zone
- Cyrtina-carbonaria sub-zone
- Gastropod Beds
- Ch. carinata sub-zone
  - Ch. Richthofeni Zone undivided
- C. isorhyncha sub-zone
- Seminula-gregaria sub-zone
  - Dyscoelosia band
- Pleurotomaria band, Athyris lepida band
- Seleneporella sub-zone

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GEOLOGICAL MAP ILLUSTRATING THE LOWER CARBONIFEROUS ROCKS OF THE FURNESS & WESTERN PORTION OF THE GRANGE DISTRICTS.

BY E. J. GARWOOD, M.A., V.P.G.S.

DUDDON ESTUARY
ANGERTON MOSS
THE DUDDON SANDS
Scalegate
Dunnerholme Head
Gunson Height
Broughton Beck
Silurian
Penny Bridge
Haverthwaite
River Leven
Low Wood
Backbarrow
Hazell Rigg
High Newton
Broughton Hall
Lindale
Castle Head
Holker
Cark
Allithwaite
Flookburgh
Kirkhead End
Humphrey Head Wood
Humphrey Head Point
Raven Winder
Low Marsh
Cowpren Point
Chapel Island
CARTMEL SANDS
ULVERSTON SANDS
LEVEN ESTUARY
KENT ESTUARY
Barker Scar
Park Head
Hampton Hall
Ashe Point
Deer Dike Moss
Old Park
Raven Barrow Point
Quarry Flat Point
Hammerside Point
Rame Farm
Dragley Beck
Newland
ULVERSTON
Gawcow
Great Urswick
Urswick Tarn
Birkrigg Common
Bardsea
Bigrigg
Ellers Beck
Sandscale Moor
Scale Beck
Park Mines
Quarry
Lindale
Yellow Hill
Canishead Priory
Triassic Rocks
Hoad Urswick
Markfield
Stainton
Newton
Bucharcan
Newbarns
Stank
Gleaston
Gleaston Castle
Gleaston Park
Gait Park
Aldingham
Aldingham Hall
Lower
Newbiggin
Aldingham
Triassic Rocks
Moor Head
Newtown
Leonard Scar
Bovcliff
Barrow
ISLE OF BARROW
Roosecote Sands
MORECAMBE BAY
LINE OF SECTION
Broughton Beck
Kempfield Hall
Limestone Quarry
HAMPSFELL BLOCK
The High
Longlands
Lindal Moor
Lindal Cote
Greenbank
Marsh Fell Gate
Marsh Fell Cote
Heathwaite
Stennerd Cottages
Kents Bank
Barker Moss
Wraysholme Island

INDEX OF COLOURS

- Upper Orbiculoidea band or base Cyrtina septosa band
- Lower
- Nematophyllum minus sub-zone
- Cyrtina-carbonaria sub-zone
- Gastropod Beds
- Ch. carinata sub-zone or Michelinia Zone undivided
- Chaetetes sub-zone
- Seminula gregaria sub-zone

Scale of One Inch to One Mile

1 0 1 2 3 Miles

Whitbarro

all

Morland

Weller & Graham Ltd ...ting, London

Fig. 3. — GENERALIZED SECTION ACROSS THE FURNESS, GRANGE, AND NORTH KENDAL DISTRICTS.

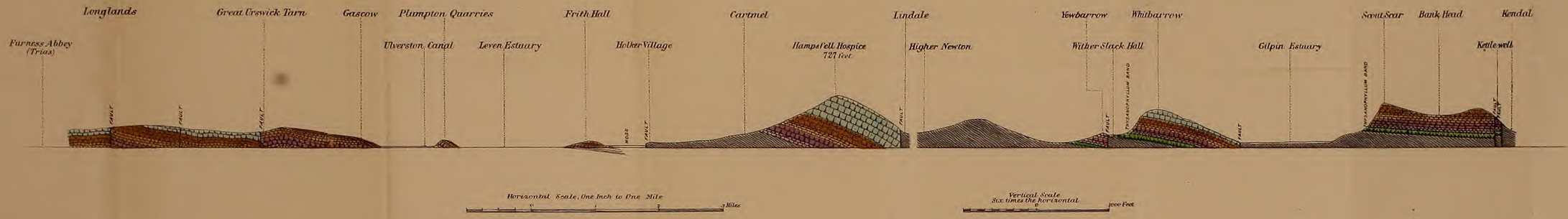


Fig. 2. — SECTION ACROSS THE RAVENSTONEDALE DISTRICT.

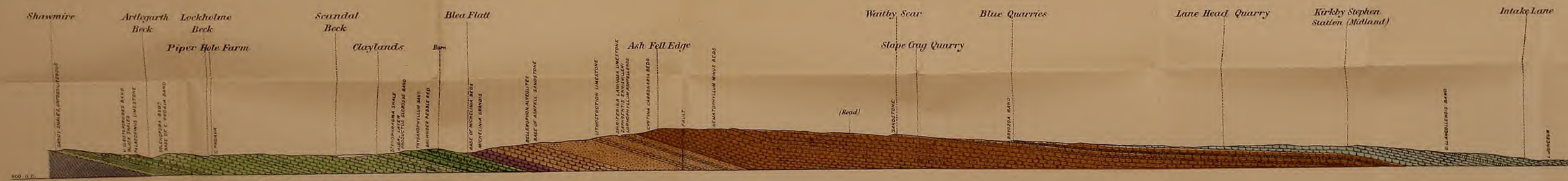
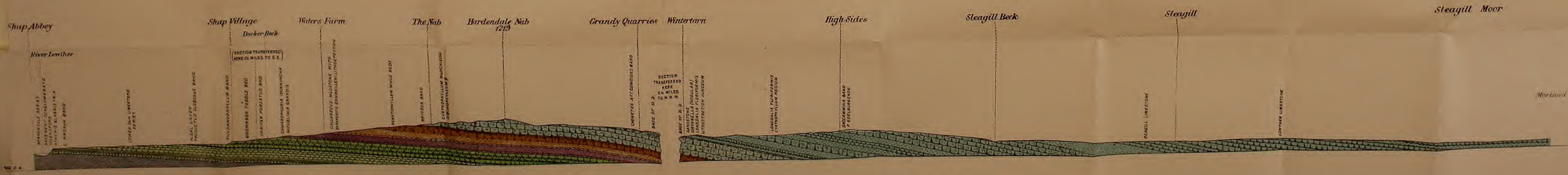


Fig. 1. — SECTION ACROSS THE SHAP DISTRICT.



District dome, as suggested by Dr. Marr. He (the speaker) thought that the evidence pointed to the upper zones having successively overlapped the lower, and that later movements had brought the portion nearest the Dent Fault within the range of denuding influences to a greater extent than the portion towards the north-west, so that the lowest beds were exposed near Ravenstonedale.

The suggestion that the Pinskey-Gill Beds might be of Devonian age added to the difficulty of interpreting the geological history of the area. Rocks of Tournaisian age were present; the red conglomerate could best be correlated with the Upper Old Red of Scotland, and yet Devonian rocks were suggested in Pinskey Gill. It would certainly be most useful if the exact position of the red conglomerate, below the bridge of Pinskey Gill, in the sequence could be determined.

Dr. Ivor Thomas considered that the correlation of the *pinskeyensis* beds with the Hamilton Group of North America, as suggested by one of the previous speakers, was very unsafe. The fossils hitherto found in the former were insufficient to warrant even an attribution of Devonian age. The correlation of the *Cleistopora* Beds with the Chemung Group by the same speaker was also somewhat startling, since there appeared to be no justification for it whatever on palæontological grounds.

The palæontology of the district under discussion was exceptionally interesting. Several of the characteristic fossils, such as *Camarotœchia proava*, *Seminula gregaria*, *Productus globosus*, etc., were so far unknown in the South-Western Province; while the occurrence of forms such as *Vaughania cleistoporoides* and other interesting corals afforded ample opportunity for important researches.

Mr. E. E. L. Dixon congratulated the Author, and was in complete accord with the conclusions, outlined in the abstract, as to the age of the dolomitization and silicification, and the conditions of deposition, that was, in lagoons, of the *Solenopora* Beds and the associated compact (amorphous-looking) limestones and dolomites. But, although the Author had succeeded in establishing a faunal succession for the North-West of England, and did not insist on the suggested correlation with the South-Western Province, the speaker asked whether the following alternative correlation of the beds referred by the Author to γC_1 had been considered.

The Sub-zone C_2, both in the South-Western Province and elsewhere (as, for instance, parts of Belgium), commenced with a peculiar shallow-water phase similar to the lagoon-deposits forming the *Solenopora* Sub-zone of the North-Western Province; at Rush (Co. Dublin) heavy conglomerates in C_2 also pointed to shallow-water conditions. Shallow water, therefore, was widespread in C_2 times, and might well have extended to the North-Western Province. Further, a γC_1 fauna such as that on which the Author relied in correlating the basal *Athyris-glabristria* Zone of the North-Western Province with γC_1 of the South-Western Province, had been found by Dr. Vaughan to continue in parts of the latter province into the lower part of C_2, in which sub-zone therefore, although it was mingled

at first with a few newcomers, it changed to the true C_2 fauna—not at the base but a short distance above. Hence it seemed possible that the *Athyris-glabristria* Zone was no lower than the base of C_2 of the South-Western Province.

This possibility, which accorded with Dr. Vaughan's view that the *Thysanophyllum-pseudovermiculare* Band at the top of the *Athyris-glabristria* Zone should be placed well up in C_2, would become a strong probability were it certain (as the Author adduced evidence for believing) that the *Spirifer-pinskeyensis* Beds are separated from the overlying *A.-glabristria* Zone by the conglomerate exposed in Pinskey Gill. For the conglomerate, and the change in the character of sedimentation which it accompanied, would together point to an unconformity; and the beds below, although of uncertain age, were by consent either Upper Devonian or Tournaisian. As no break, apparently, was known to occur in the Upper Devonian-Tournaisian sequence, whereas in the South-Western Province the mid-Avonian unconformity existed in places at the top of the Tournaisian, and the Viséan (the base of which is C_2) transgressed across various lower horizons on to pre-Carboniferous rocks, an unconformity, if existent, at the transgressive base of the *Athyris-glabristria* Zone would probably be this mid-Avonian unconformity, and the zone itself, despite its Tournaisian aspect, would accordingly be correlative with the lower part of C_2. The *A.-glabristria* Zone was shown by its fauna to lie in or near C_1, but its exact position might, possibly, be best determined by a comparison of the earth-movements of Avonian time in the North-Western Province with those in other areas.

The Author thanked the Fellows for the cordial reception which they had given to his paper. In reply to Dr. Vaughan and Mr. Dixon, who referred to the age of the beds below those in which *Michelinia* occurred in the north, that was, from the *Thysanophyllum* Band downwards, he remarked that the succession which he had established in the north-west was essentially a local classification, and he did not wish to press unduly the correlation of the beds with those in the Bristol area which he had suggested in the last column of the table. He hoped that any value that the work might possess would be judged independently of such correlation; at the same time, he thought it improbable that the whole of the succession in the north could be included in C_2, and was inclined to think that a certain amount, at all events, of C_1 of the Bristol succession was represented by the lowest beds above the conglomerate in the Shap area. He would like to add that he had frequently consulted Dr. Vaughan with regard to the equivalents of these beds in the Bristol area, and he had always been under the impression that Dr. Vaughan agreed with the correlation suggested in the table. He did not quite understand Dr. Vaughan's present contention, that there was nothing older than C_2 of the Bristol area in the succession which he had described.

The Author thought that he had dealt in the paper itself with most of the other questions raised in the course of the discussion.